Brookhaven Forum 2015: Status of the CMS Experiment

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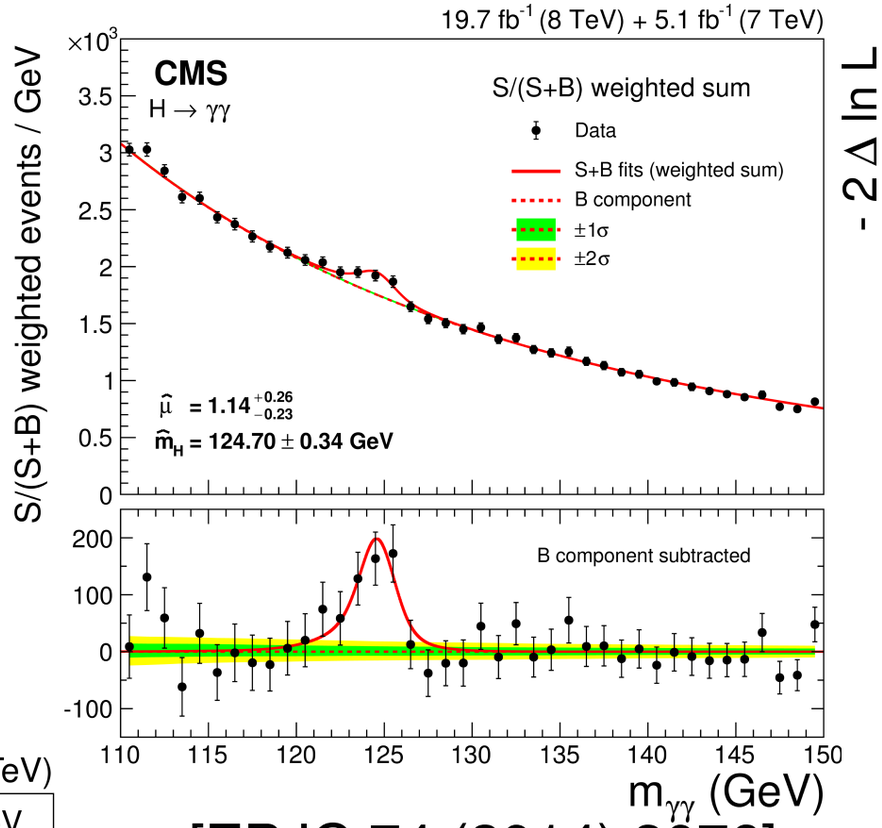
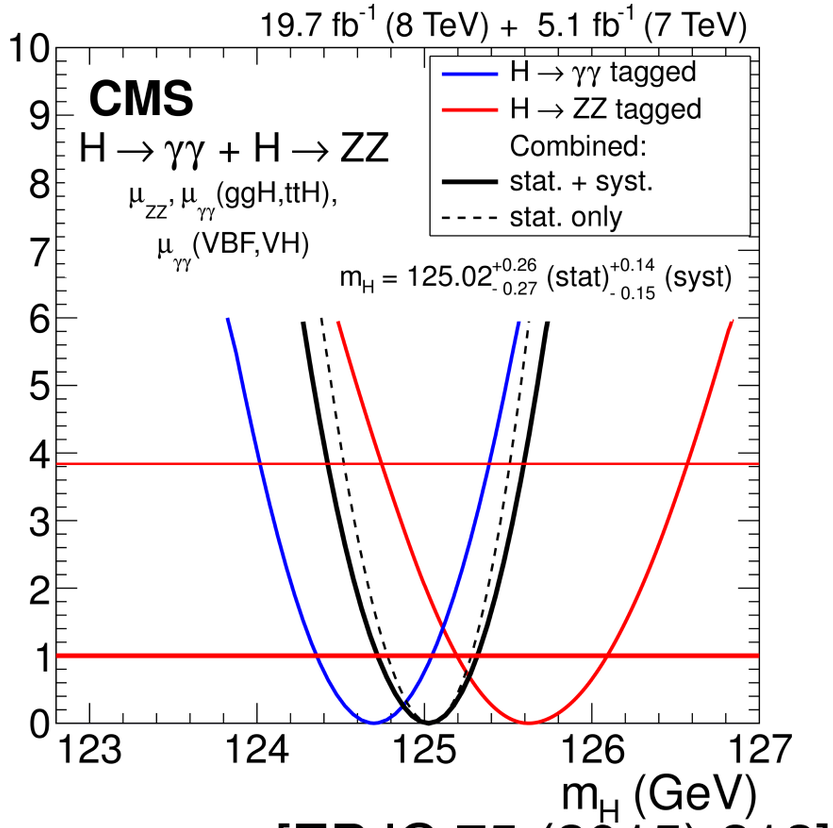
RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

Run 1

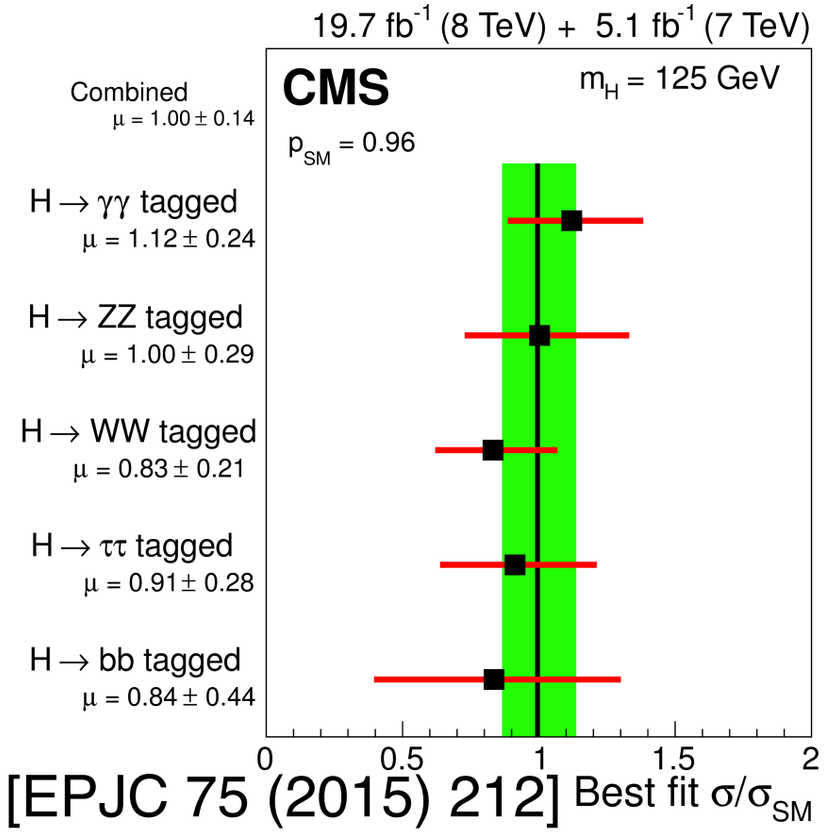
Higgs Boson



[EPJC 74 (2014) 3076]



[EPJC 75 (2015) 212]

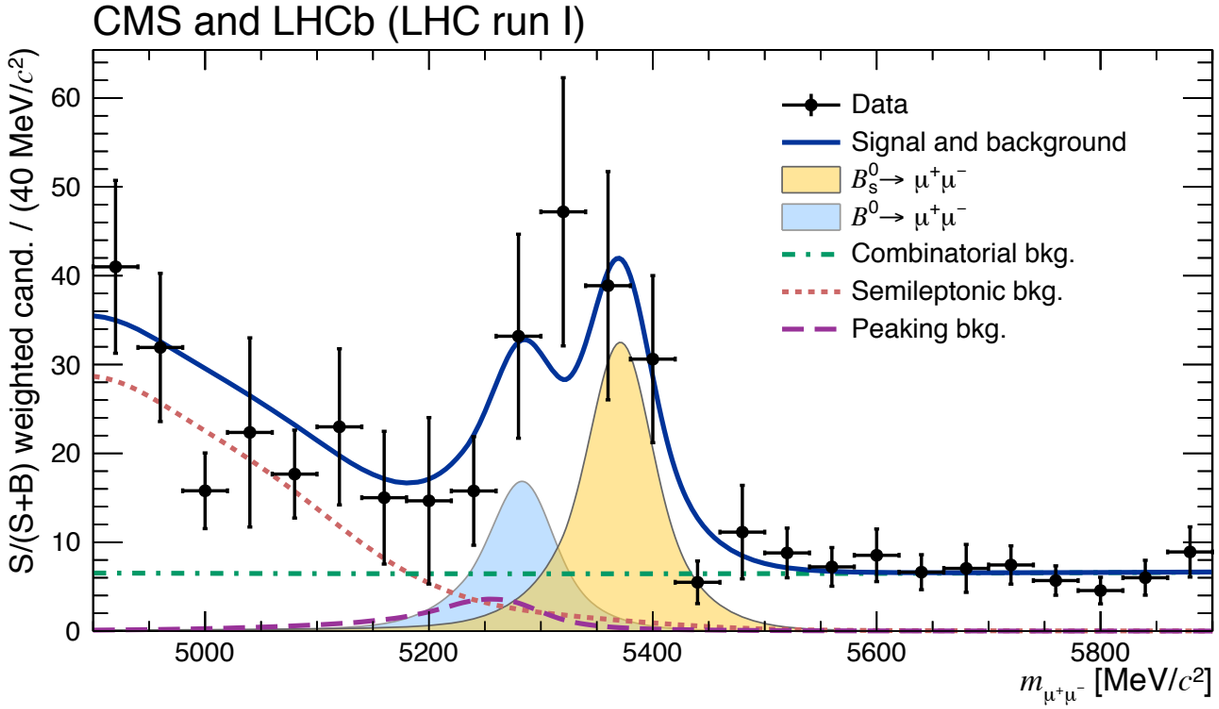


[EPJC 75 (2015) 212]

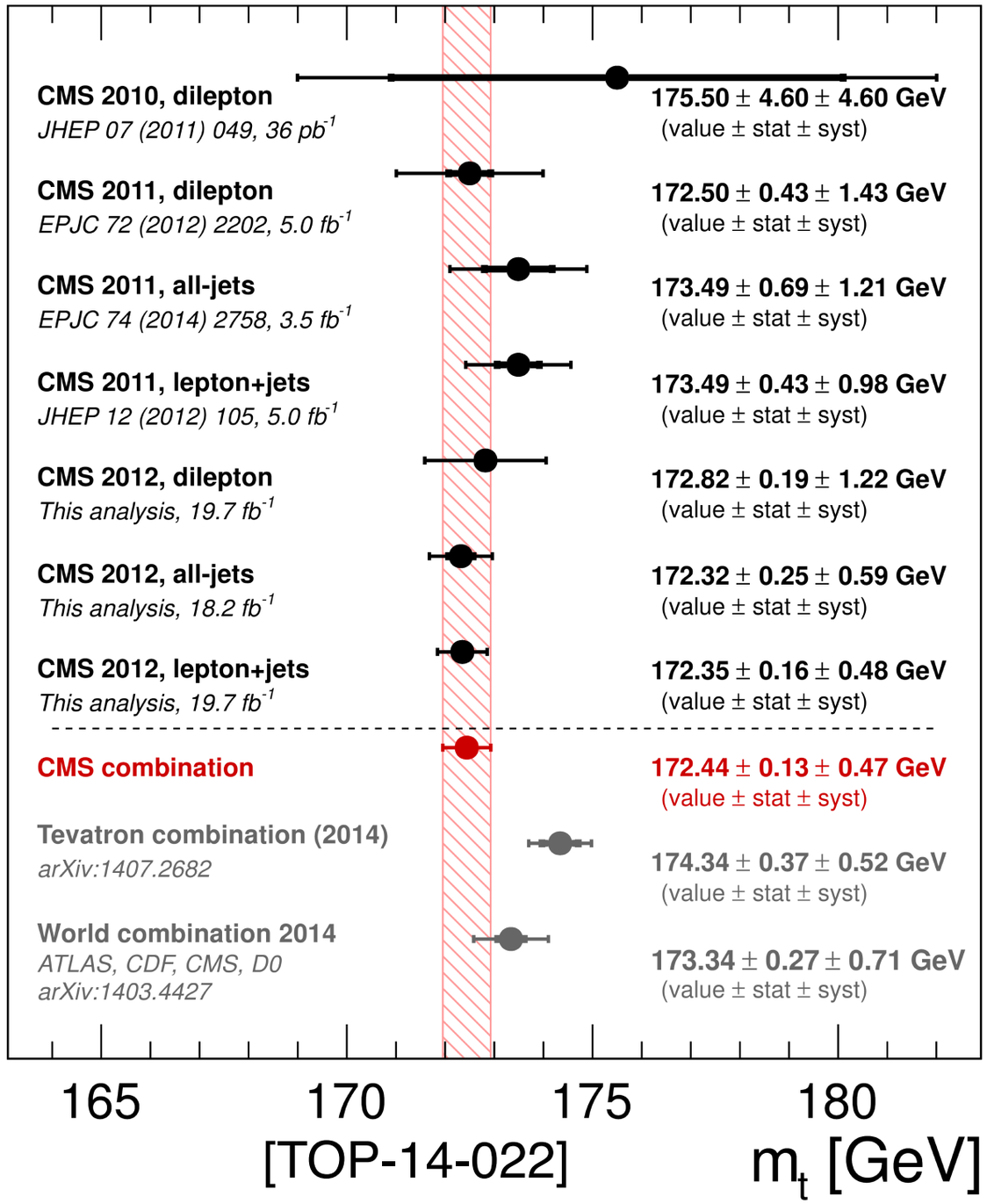
- Discovered a Higgs boson with 125 GeV and xs/couplings in line with the SM expectation

Top and B Physics

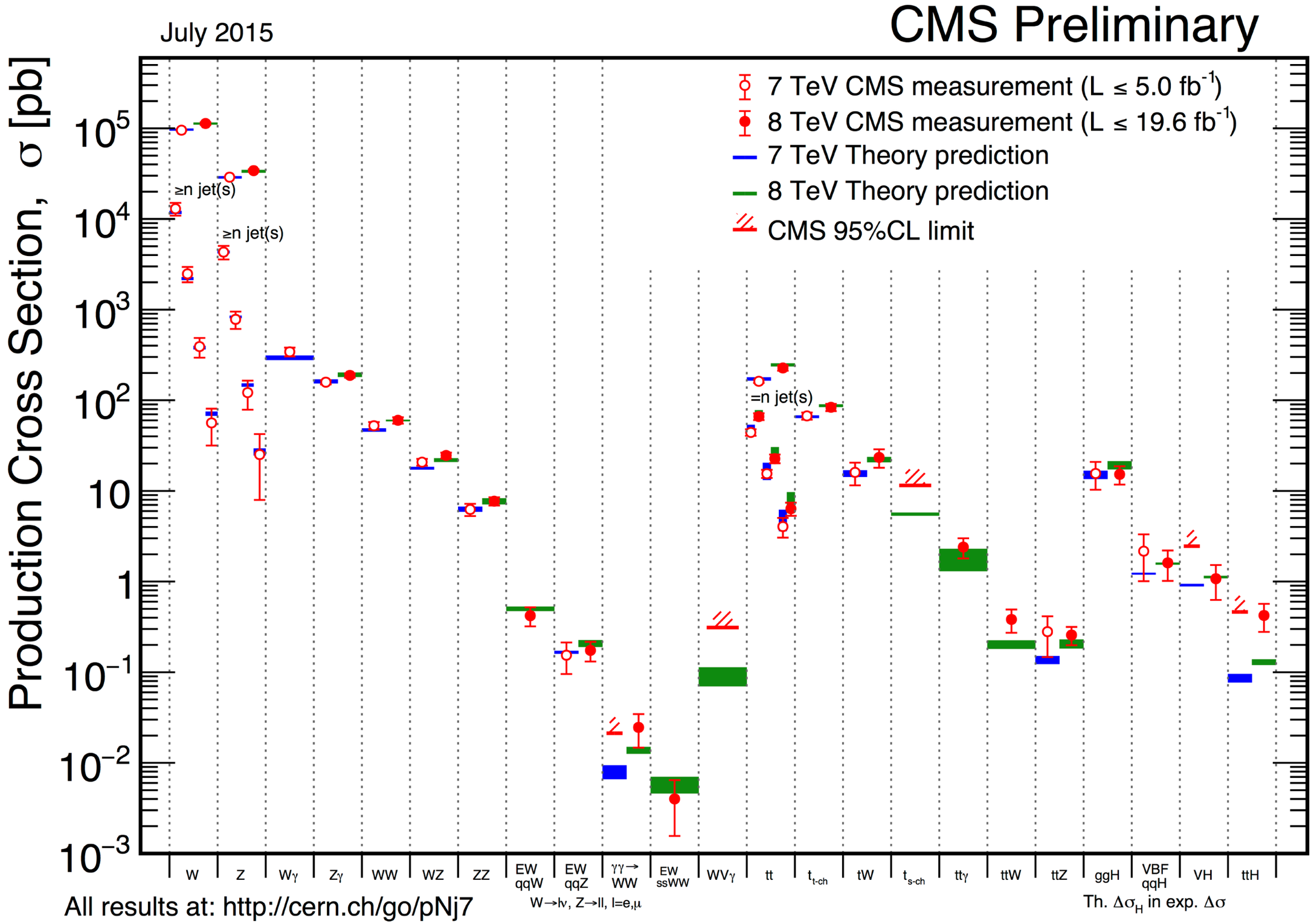
- leading mass measurement of the top quark
  - dominated by theoretical and systematic (JES) uncertainties
- First observation of the $B_s \rightarrow \mu\mu$
  - combined publication with LHCb in Nature



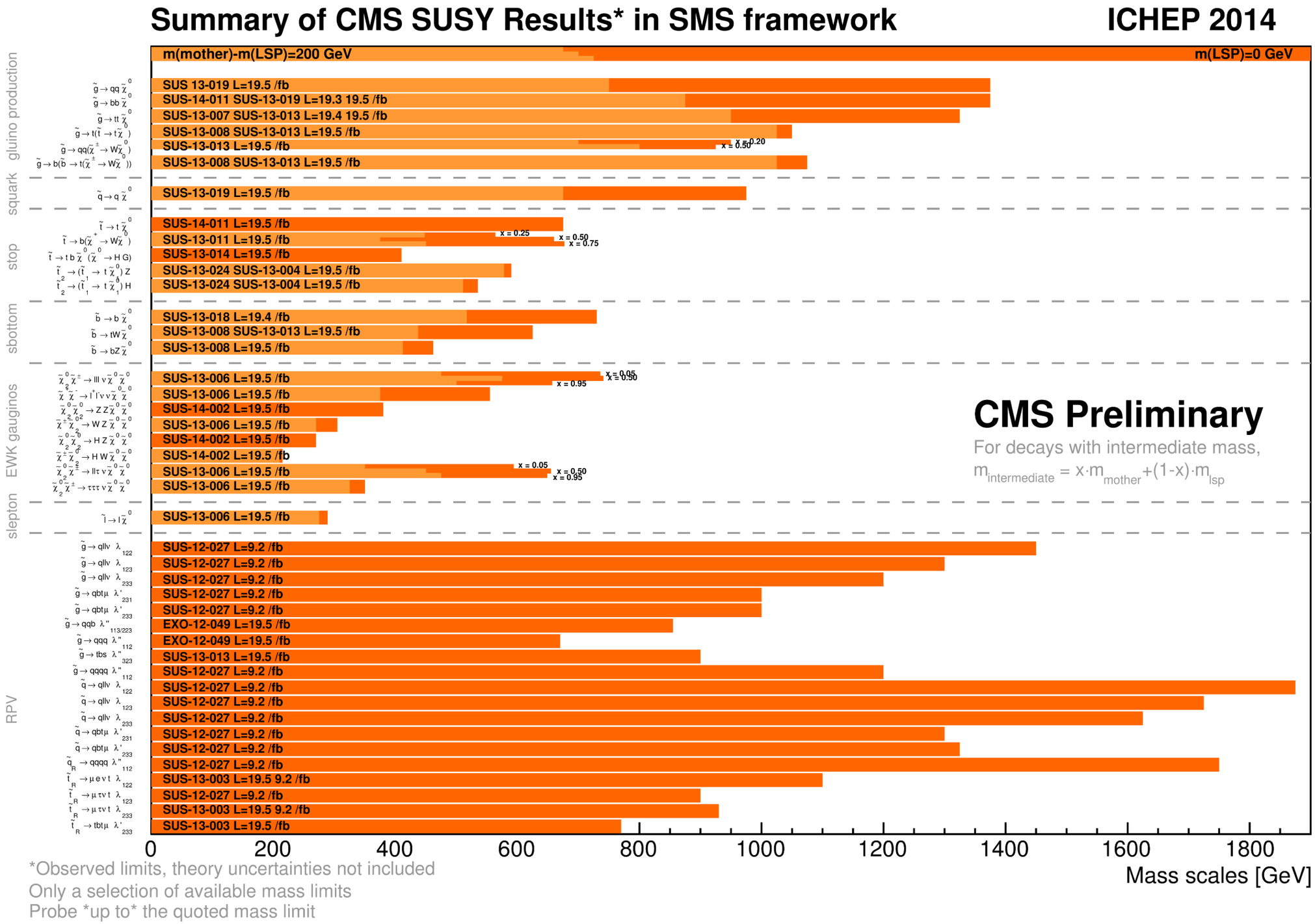
[Nature (2015) 14474]



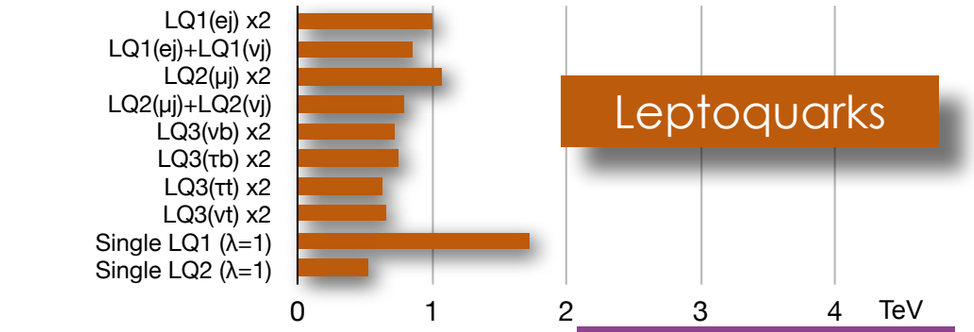
THE REST OF THE STANDARD MODEL

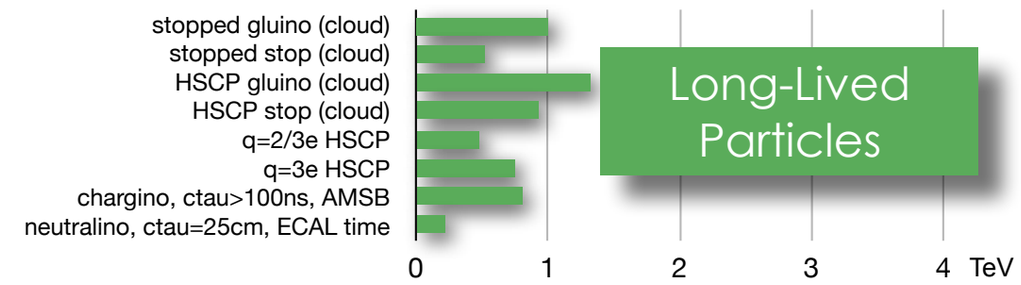


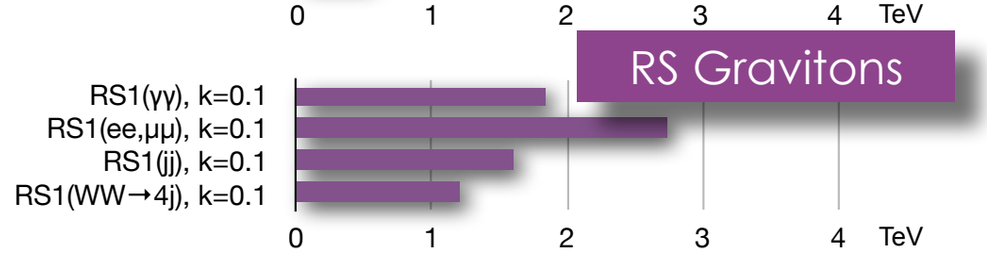
LOTS OF SEARCHES…

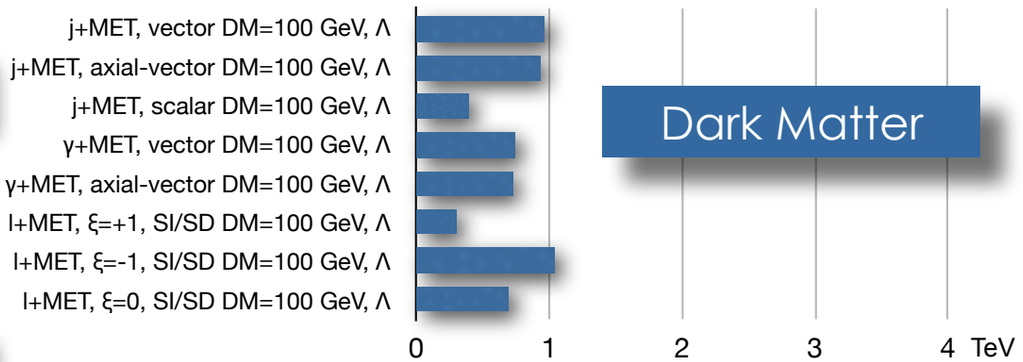


LOTS AND LOTS OF SEARCHES…

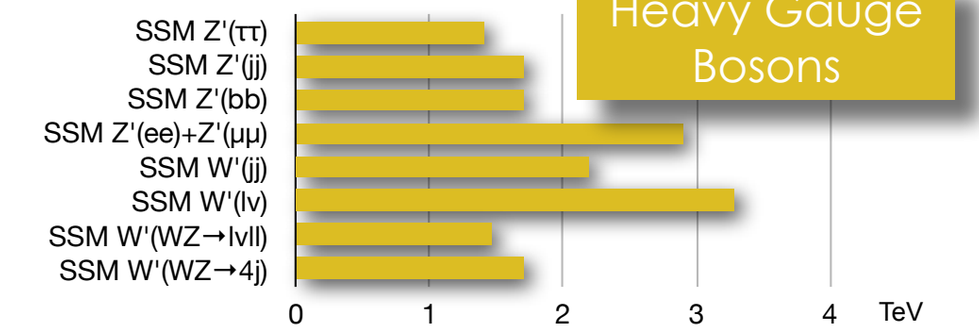


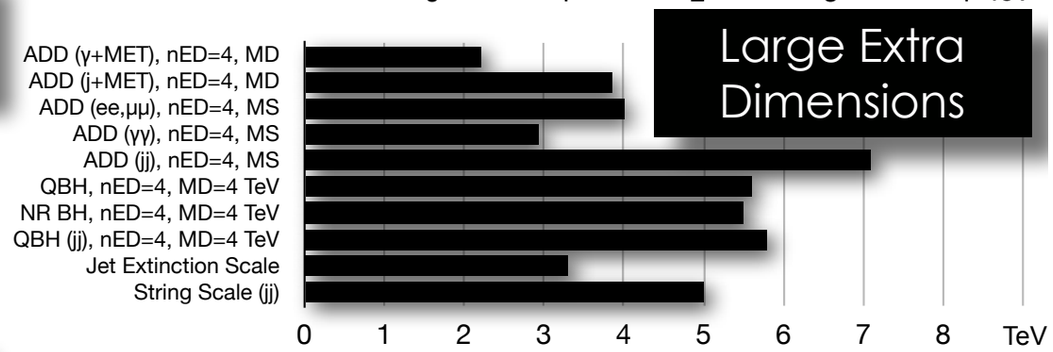


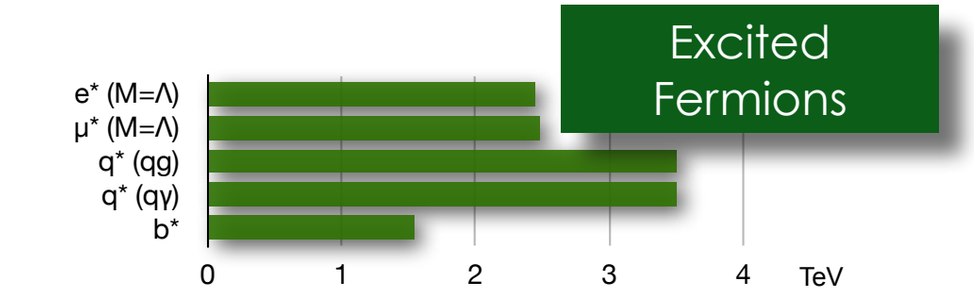


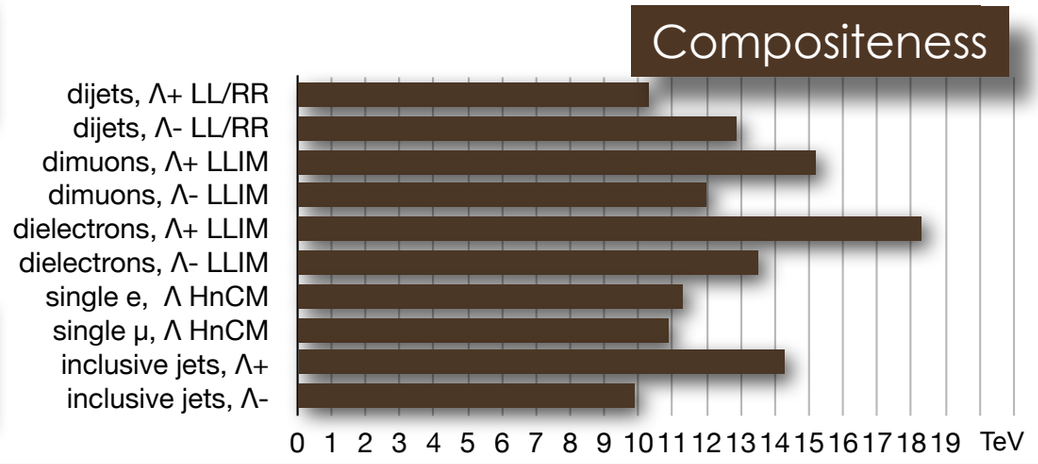


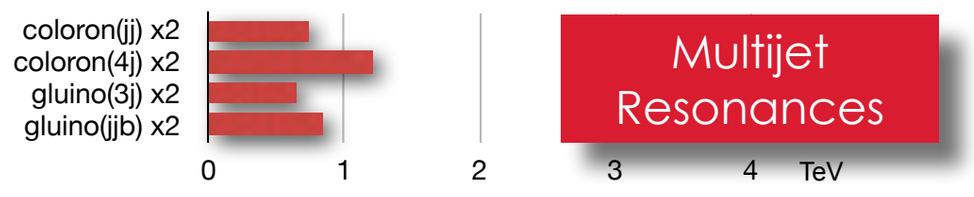
CMS Preliminary





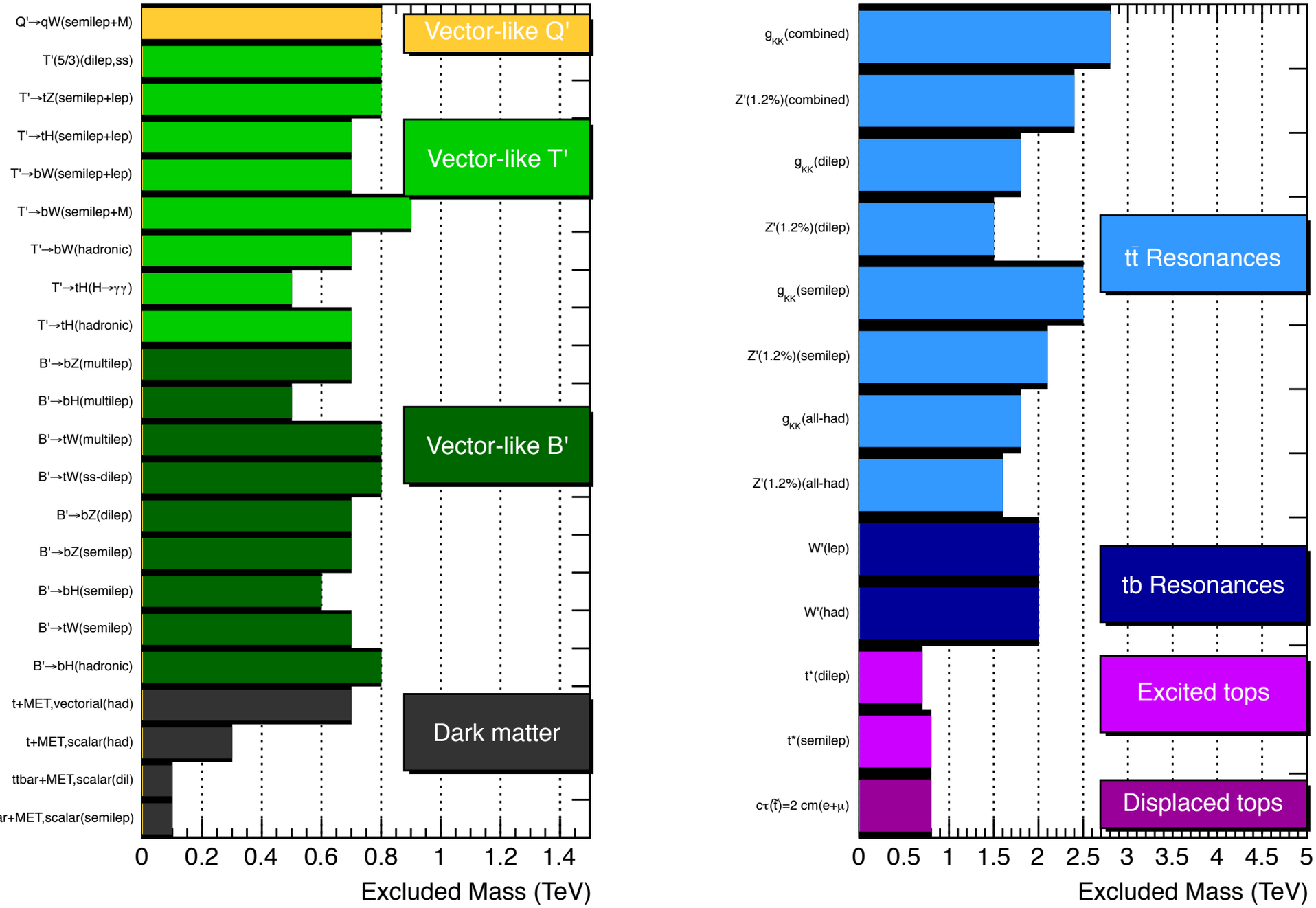






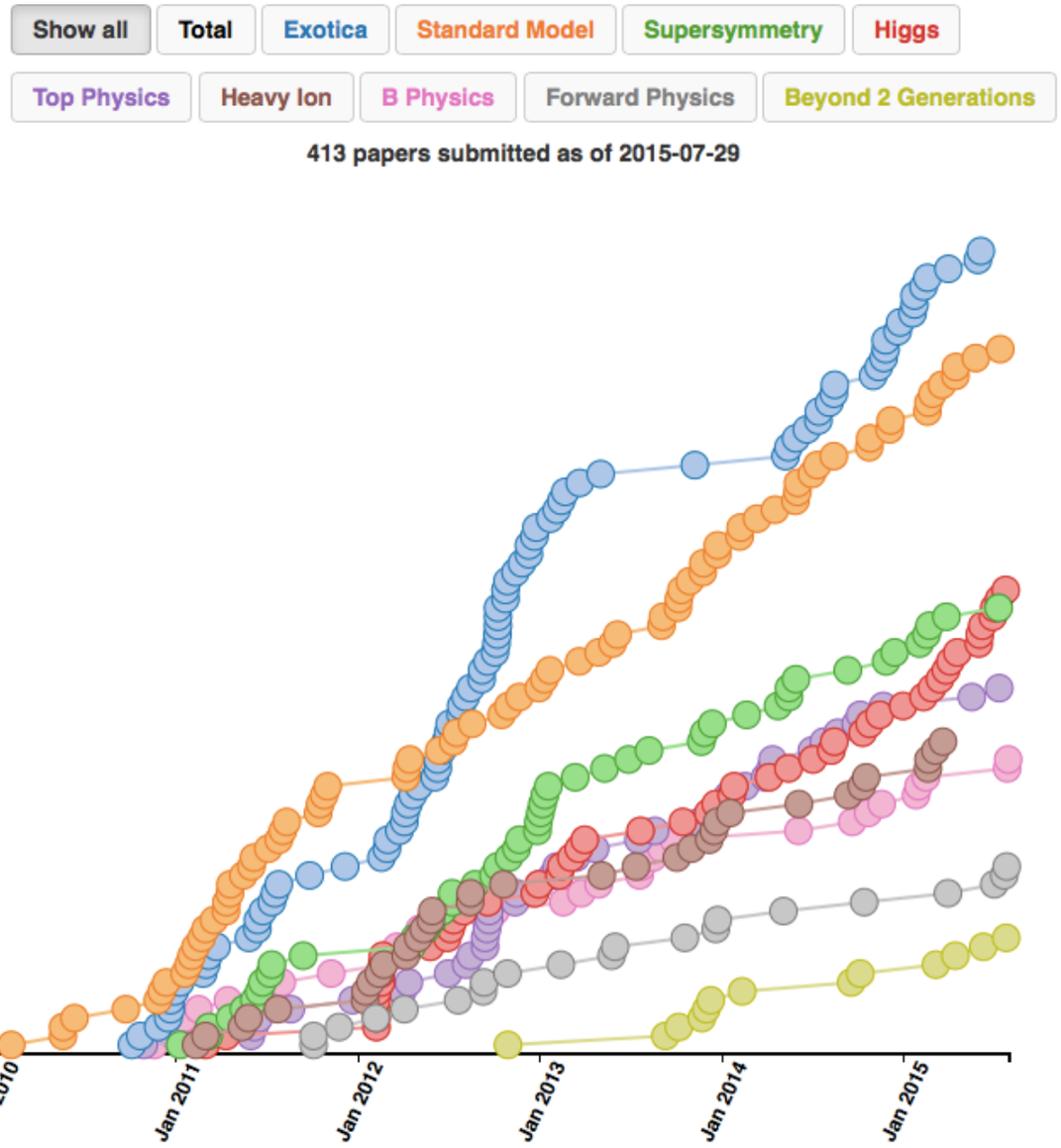
CMS Exotica Physics Group Summary – Moriond, 2015

NO SERIOUSLY…



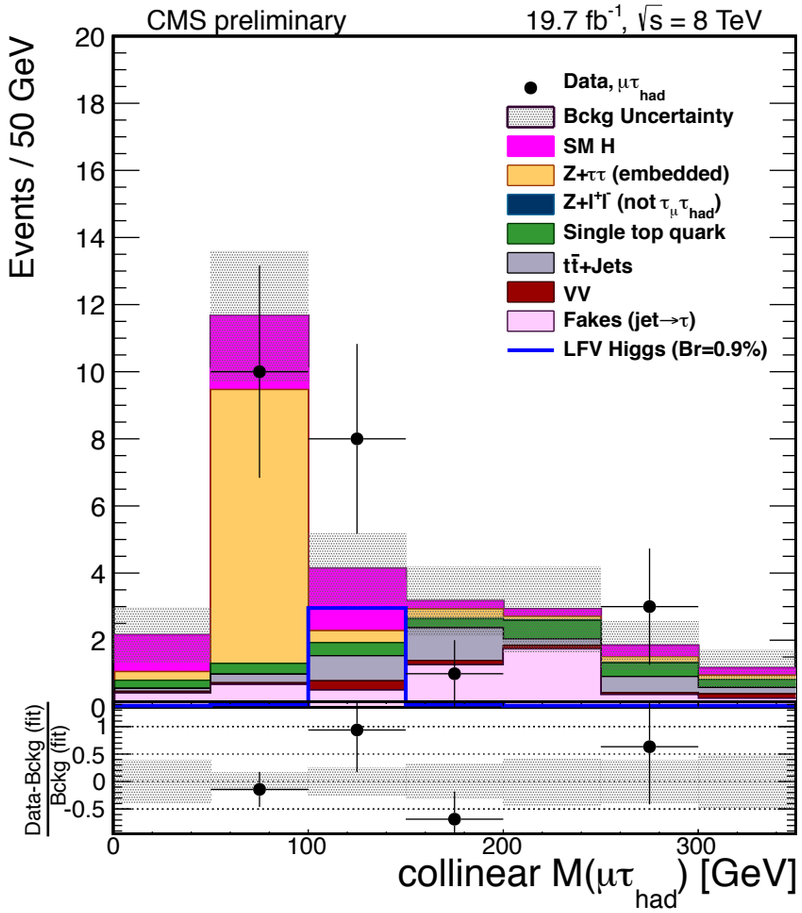
The Run I Legacy

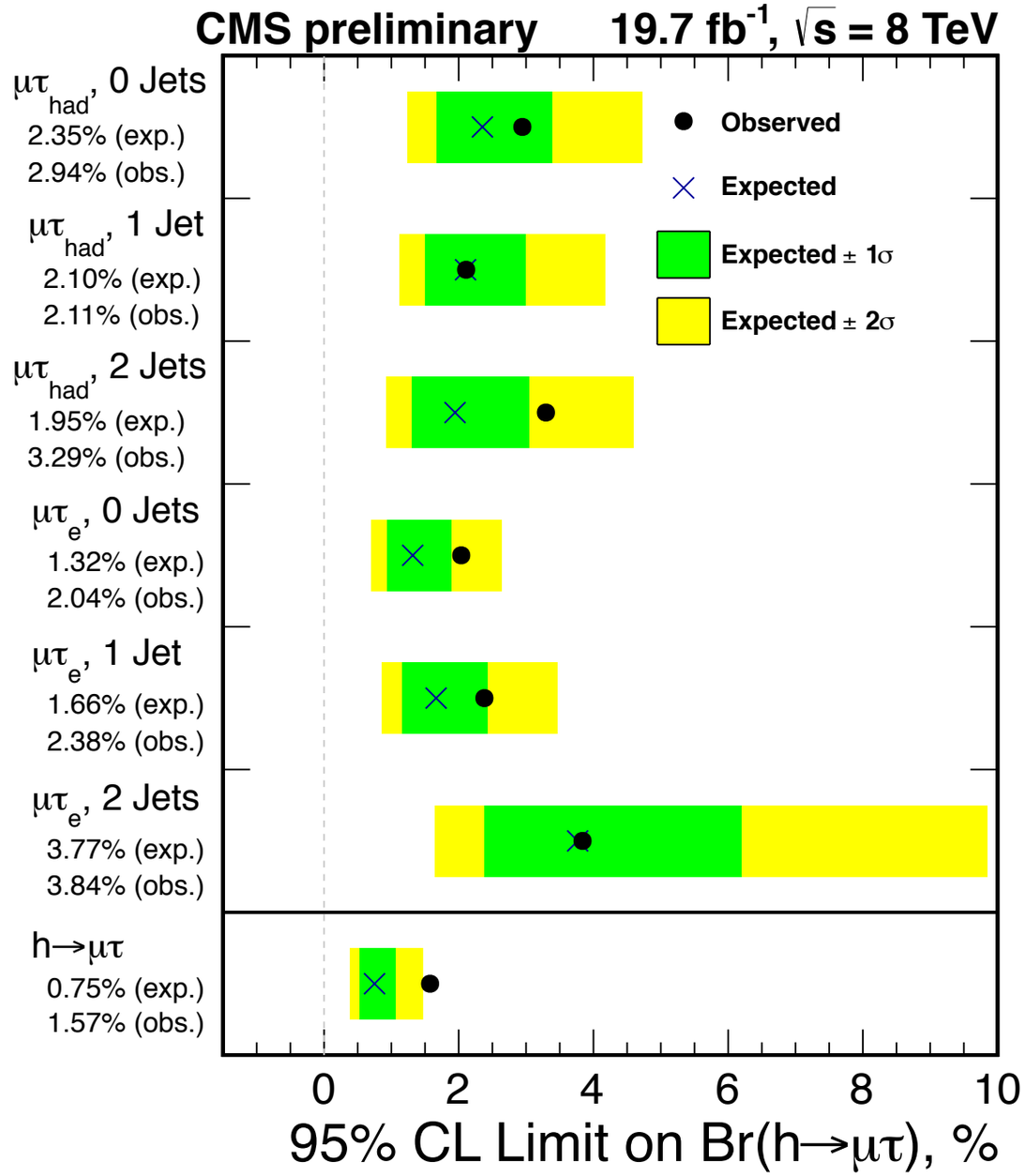
- > 400 papers have been submitted on physics results from CMS
  - Are there any excesses?



LFV Higgs Decays

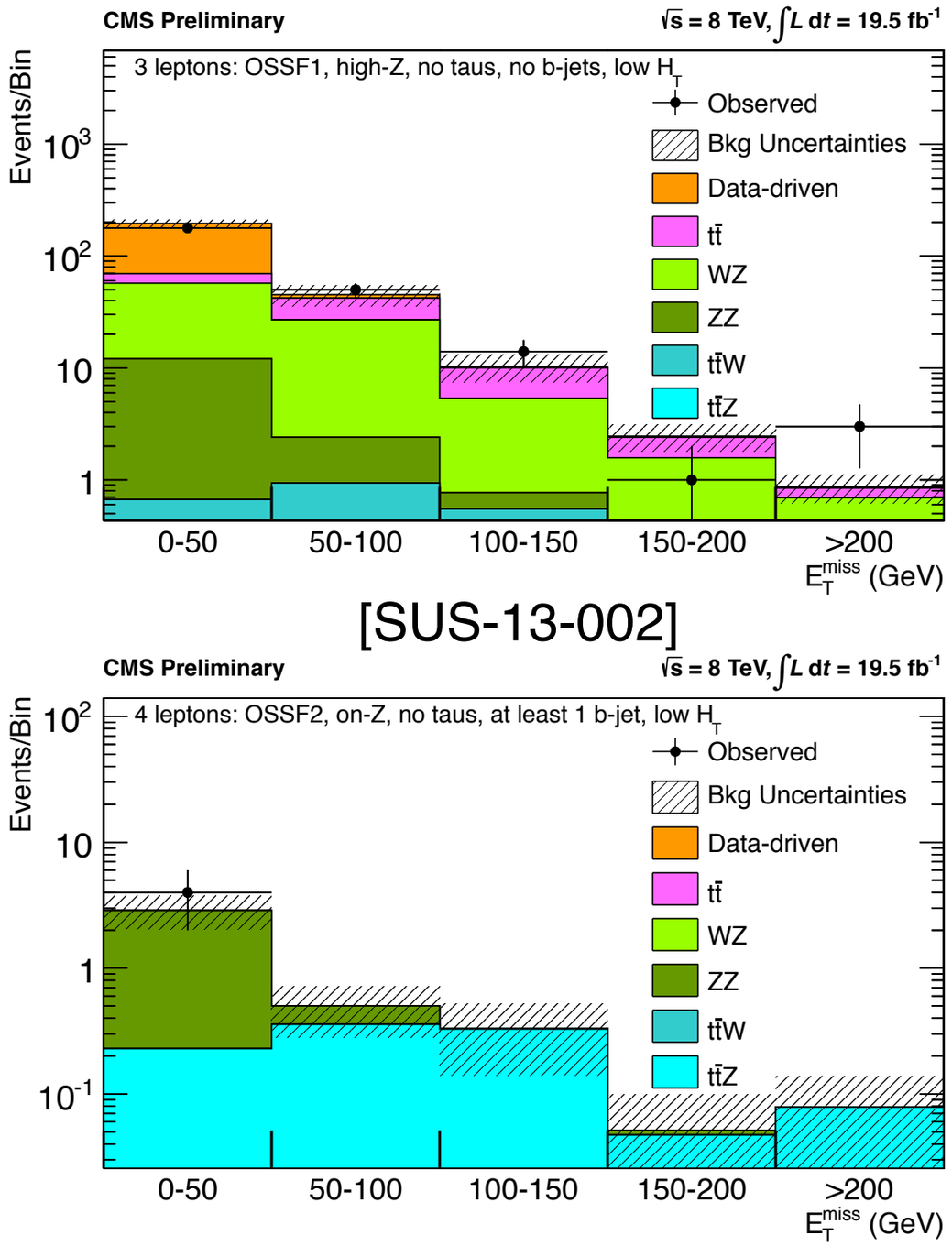
- in the search for H→μτ we see a ~2.5σ excess
  - both hadronic and leptonic taus are affected
  - no excess in corresponding H→eτ final state





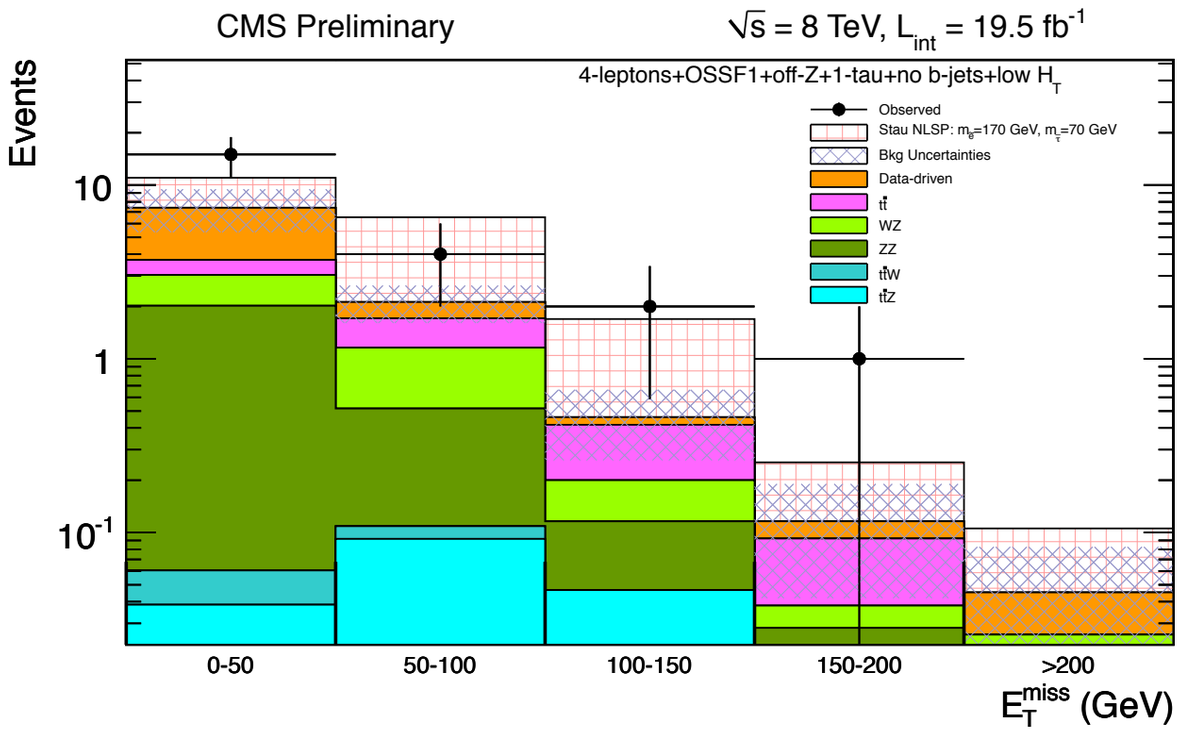
MULTILEPTON SEARCHES

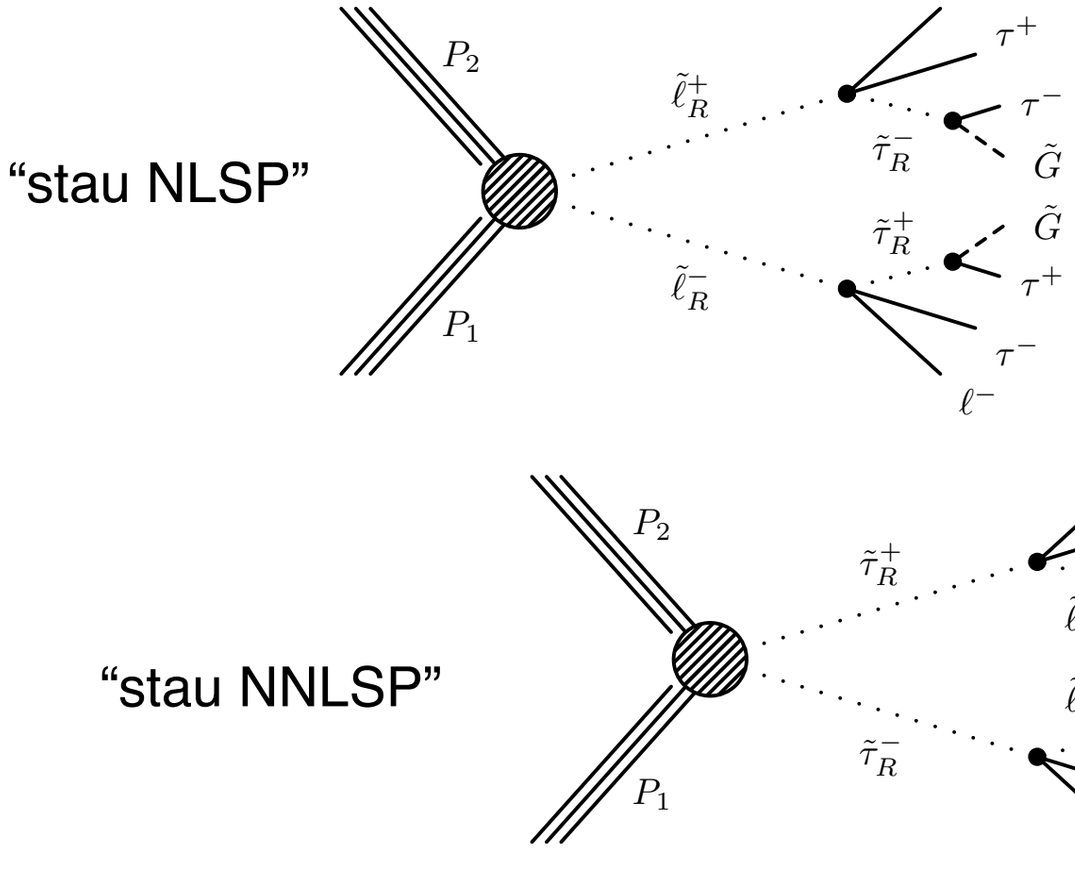
- Search for anomalous multilepton production establishes paradigm of "high resolution" searches at CMS
  - Emphasized **binning** rather than cutting on events with **≥3 isolated leptons (e or mu)**
    - ME_T and H_T
    - number of leptons
      - pT thresholds are 20,10, & 10 GeV
    - number of taus
    - number of b tags
    - # of opposite-sign same flavor (OSSF) lepton pairs
    - on/off shell Z

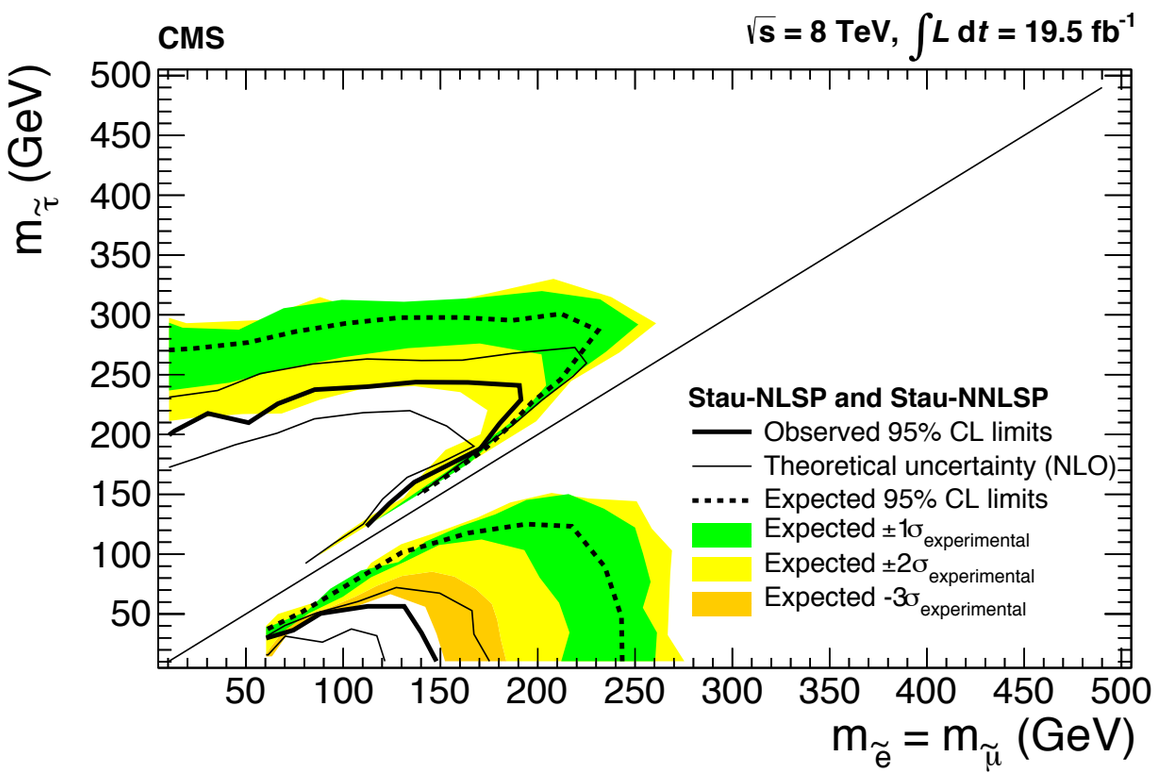


STAU (N)NLSP?

- Broad excess in 4 lepton events with…
  - 1 tau
  - off-shell Z(ee or uu)
  - no b jets
  - H_T<200 GeV



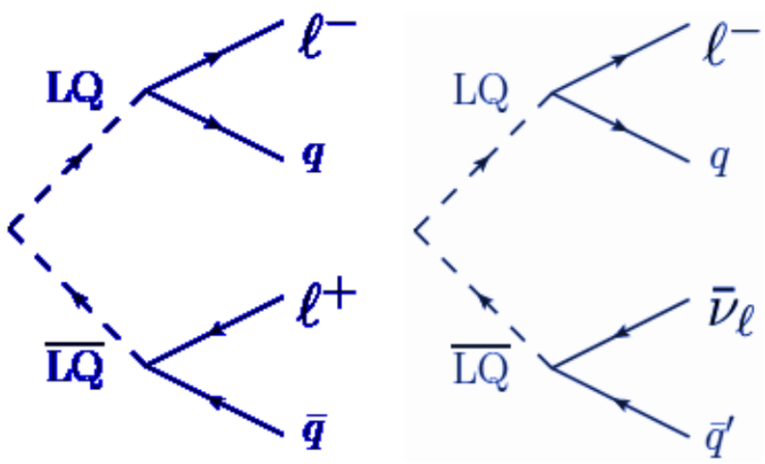




1st Generation Leptoquarks

- Search for 1st generation LQs in eejj and evjj final states
  - optimize cuts for individual LQ mass hypotheses on M(l,ν), M(ll), S_T, MET to suppress backgrounds
    - saw broad excess in both channels for a 650 GeV LQ mass hypothesis

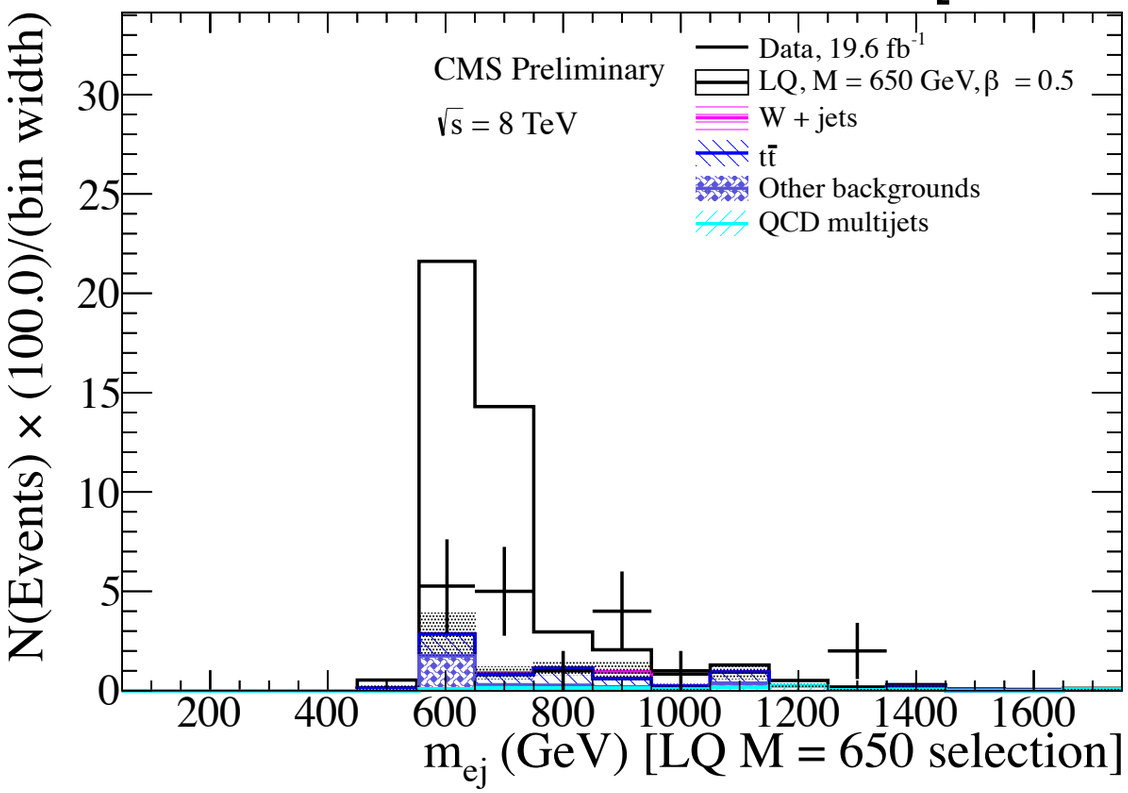
β = branching fraction to the lq final state

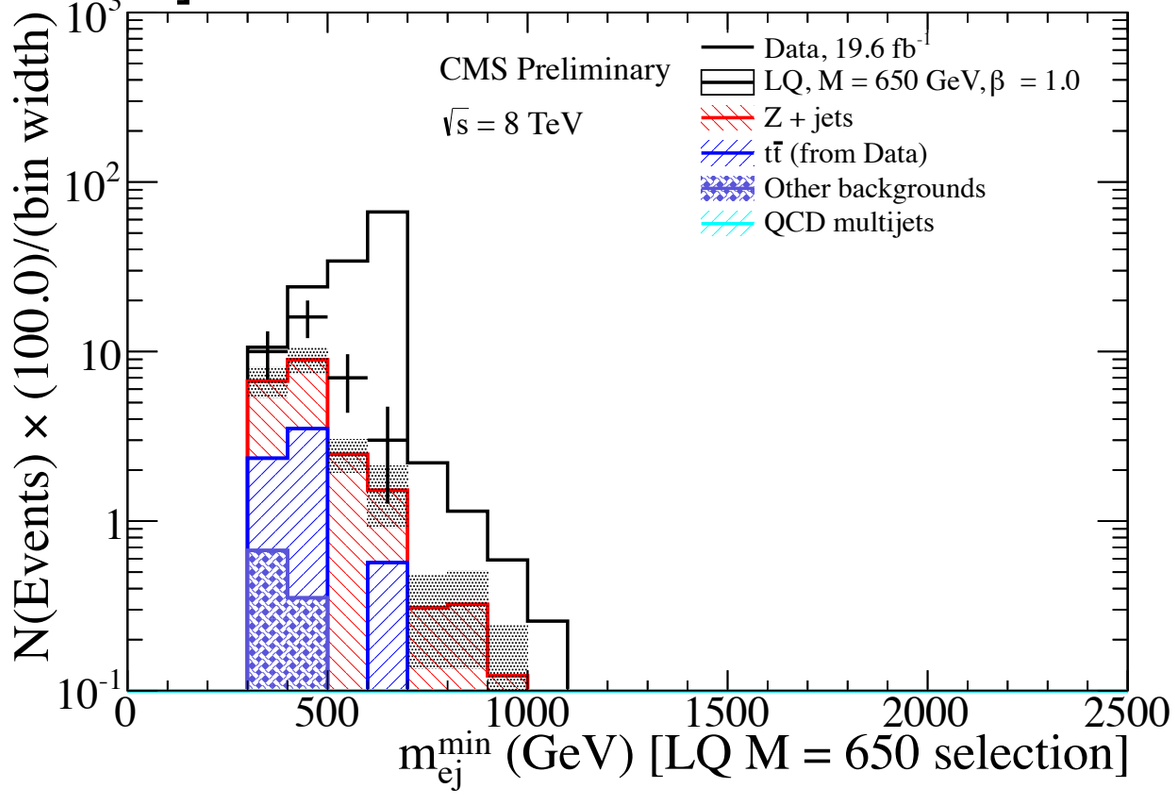


LQ1, LQ2

$\ell = e, \mu$

[EXO-12-041]

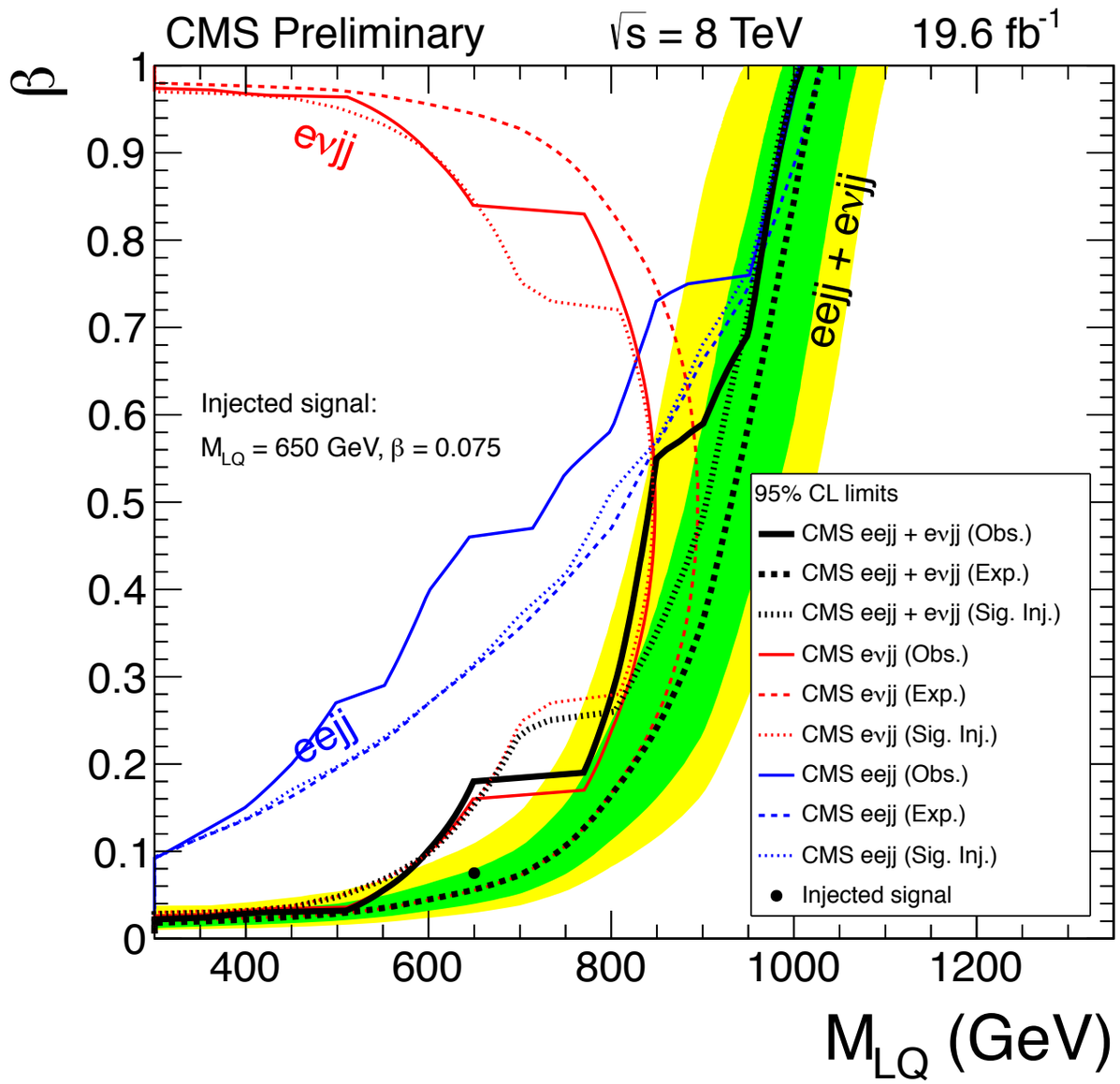




1ST GENERATION LEPTOQUARKS

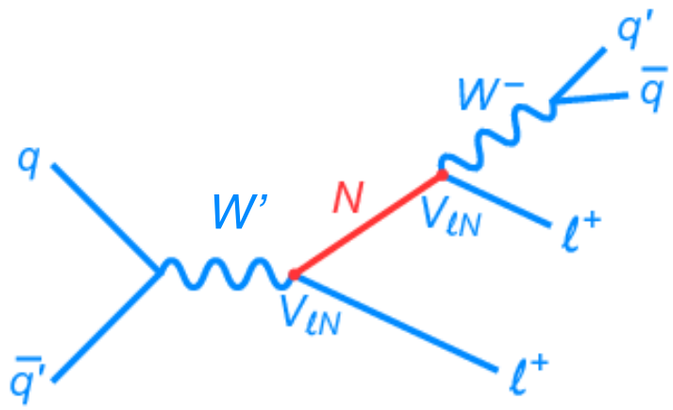
- Very difficult to reconcile with a LQ hypothesis
  - kinematics are too broad (no peak structure)
- Other possibilities?
  - several propsals, e.g.: arXiv: 1410.5947, arXiv:1408.5439, arXiv:1408.1082, arXiv: 1407.4466

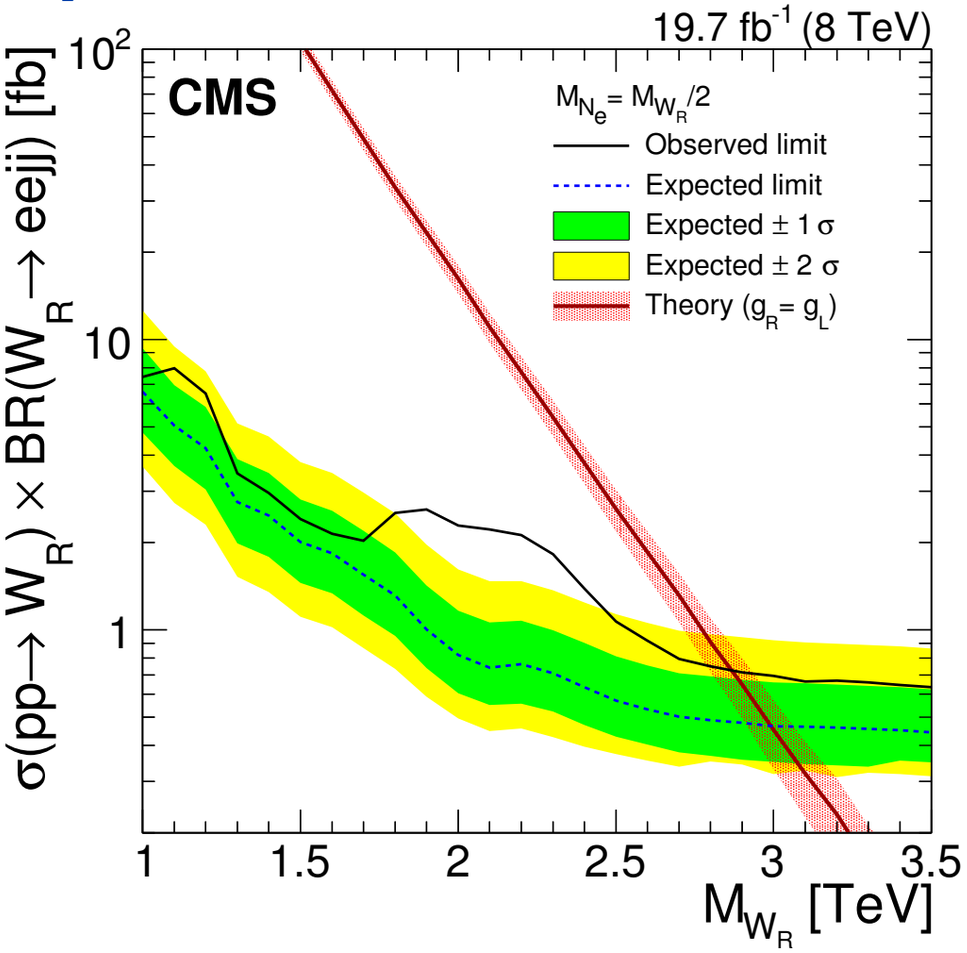
[EXO-12-041]

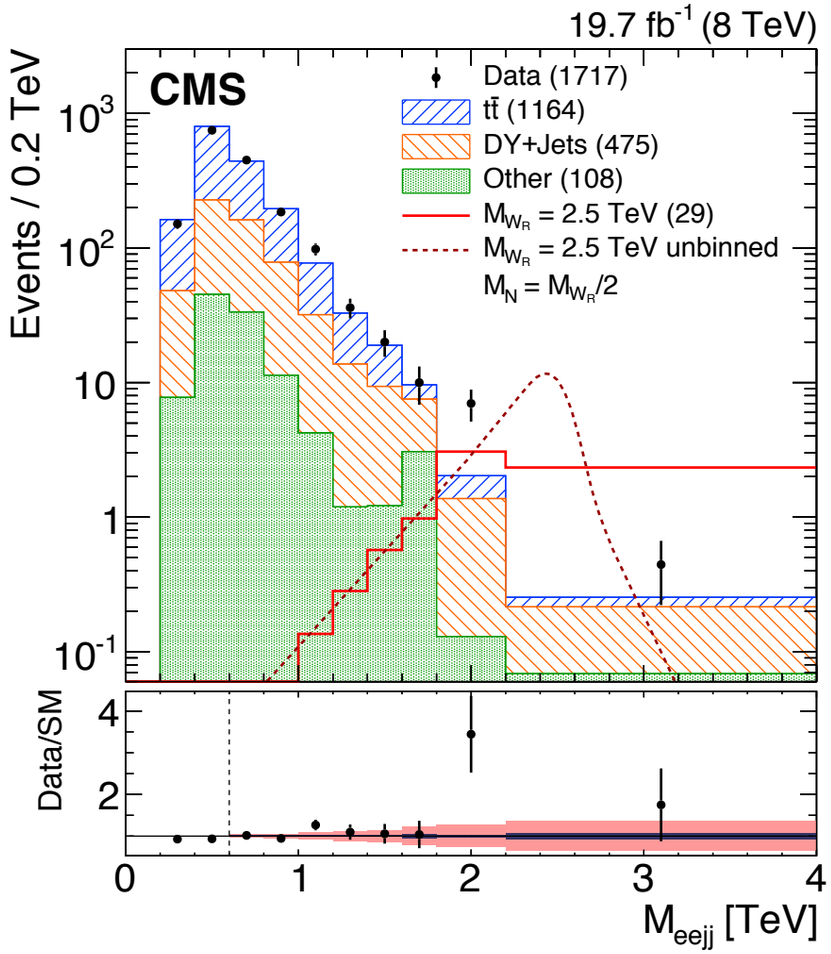


W' AND HEAVY NEUTRINO

- Interestingly, a search motivated by W' decays through heavy neutrinos also exhibited an excess in the same (eejj) final state
  - Search looks for a bump in the eejj invariant mass
  - there is little overlap in events between this and the LQ analysis

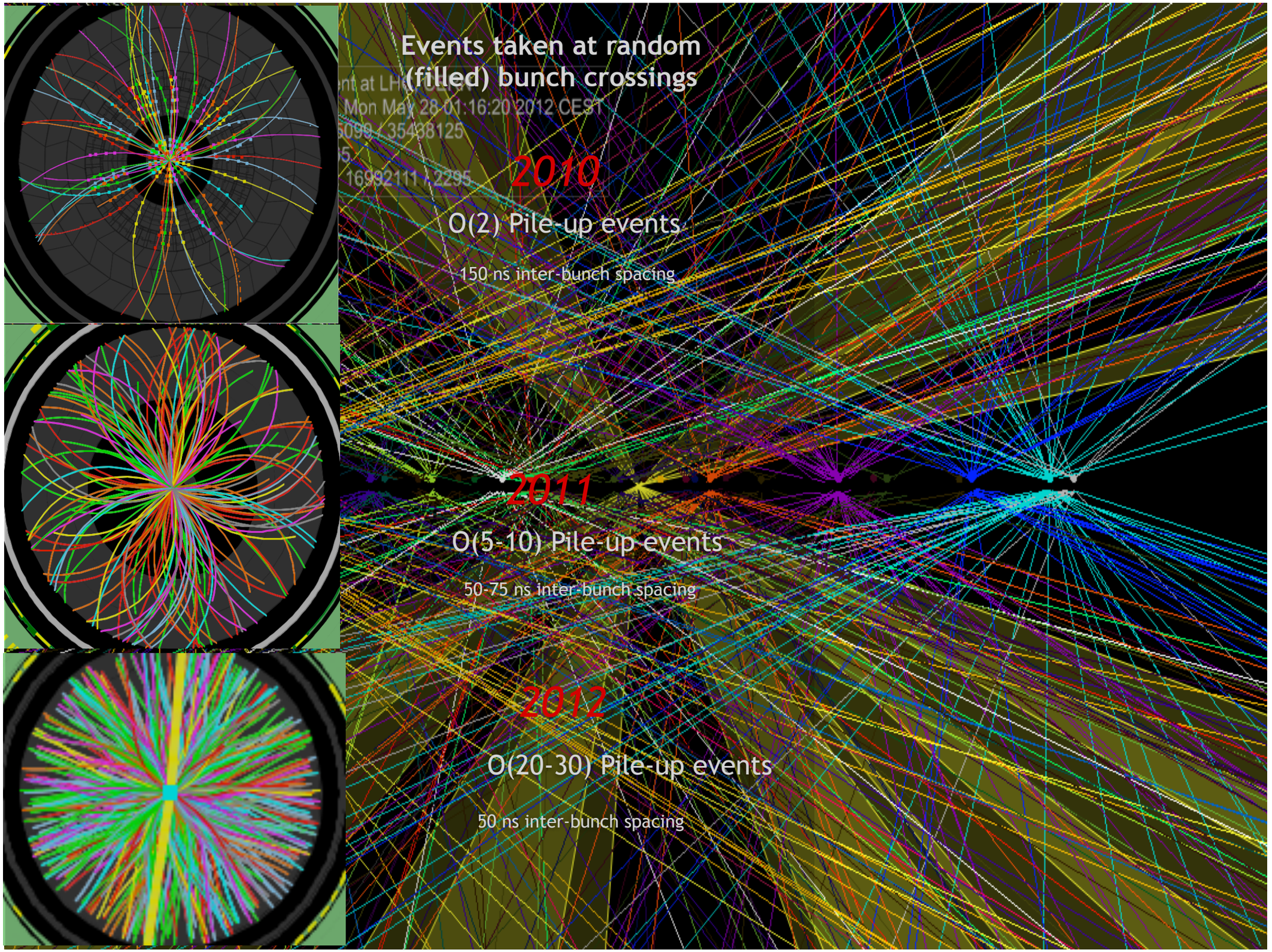






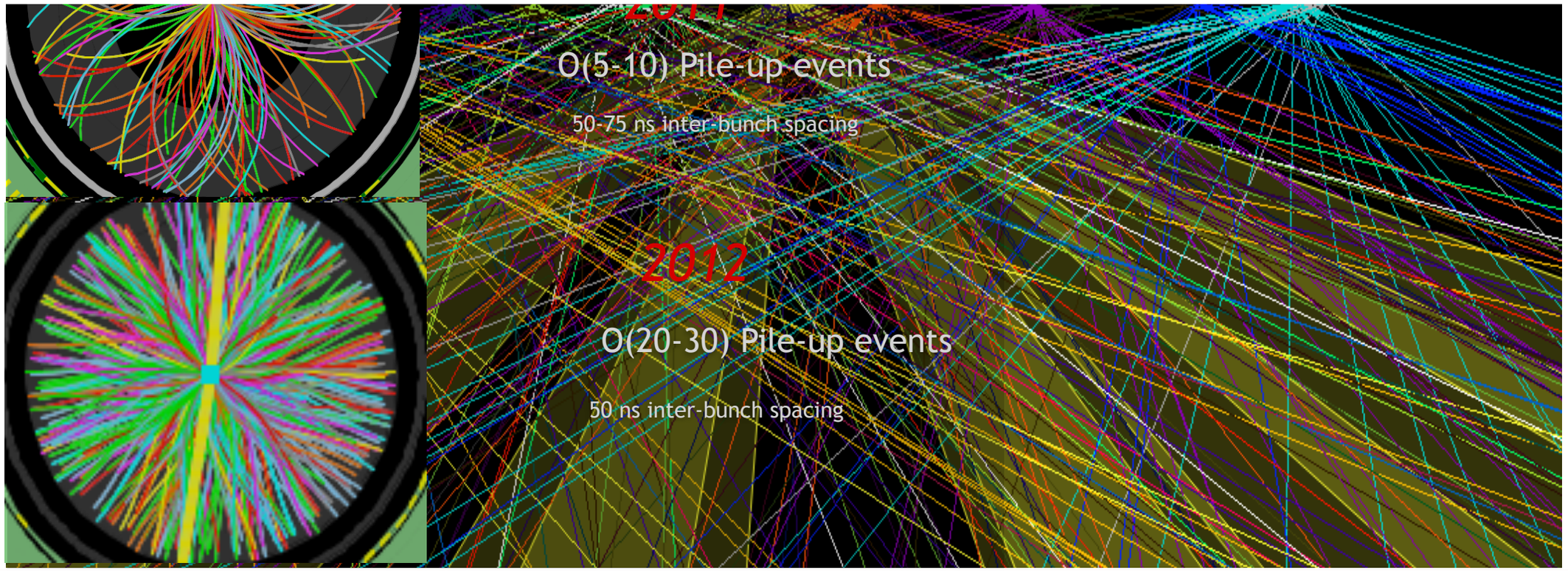
Long Shutdown 1

The Pileup Challenge

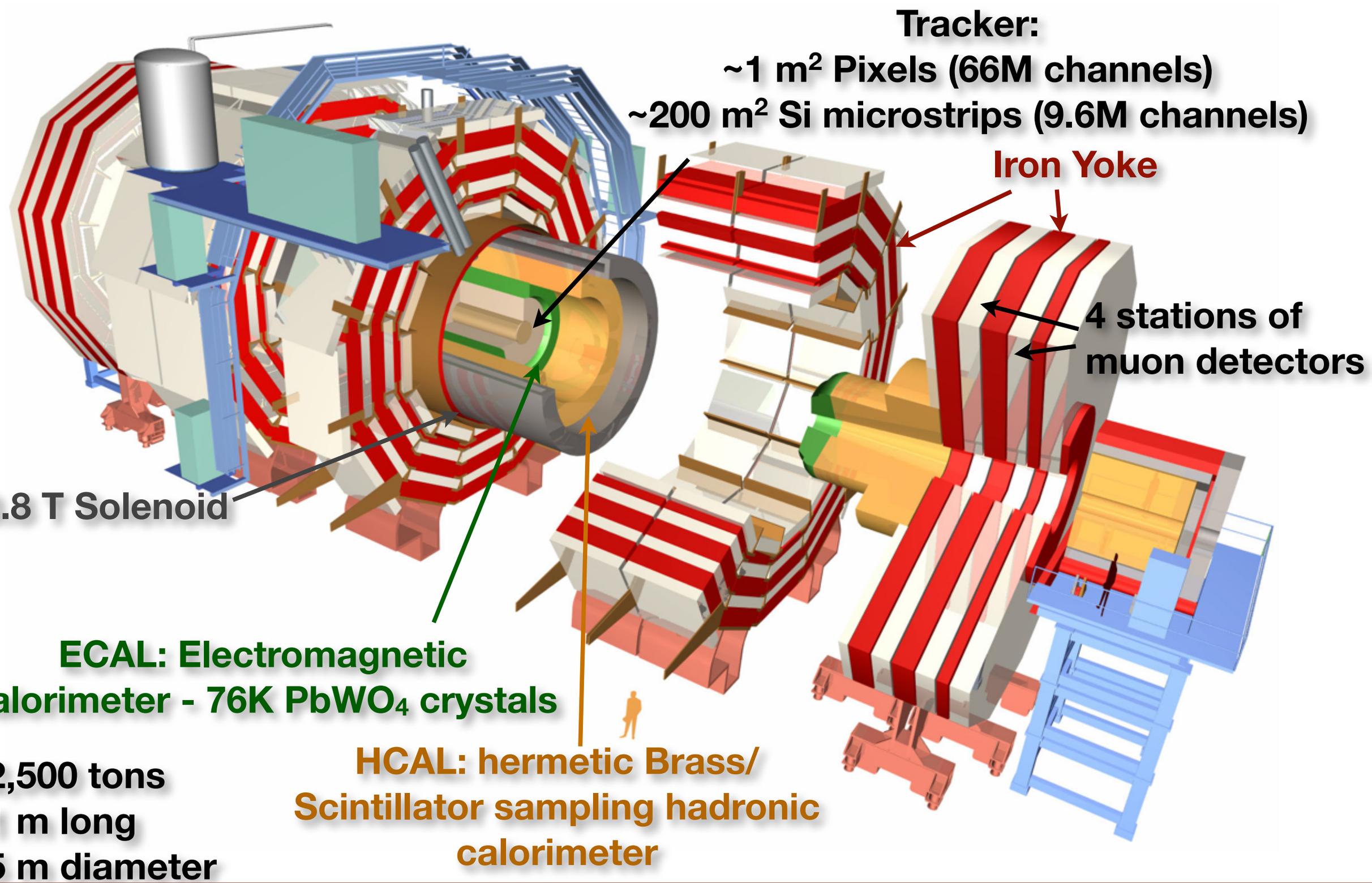


The Pileup Challenge

Period	N_{bunch} [10^{11}]	ε^* [μm]	k	β^* [cm]	L [$cm^{-2}s^{-1}$]	<μ>	Days(*)	$\int L$ [fb^{-1}]
50 ns	1.2	2.2	≈1370	80	5.3×10^{33}	30	21	≈1
25 ns / 1	1.2	2.5	≈2500	80	8.1×10^{33}	26	44	≈4
25 ns / 2	1.2	2.5	≈2500	**40**	14.7×10^{33}	45	46	≈13



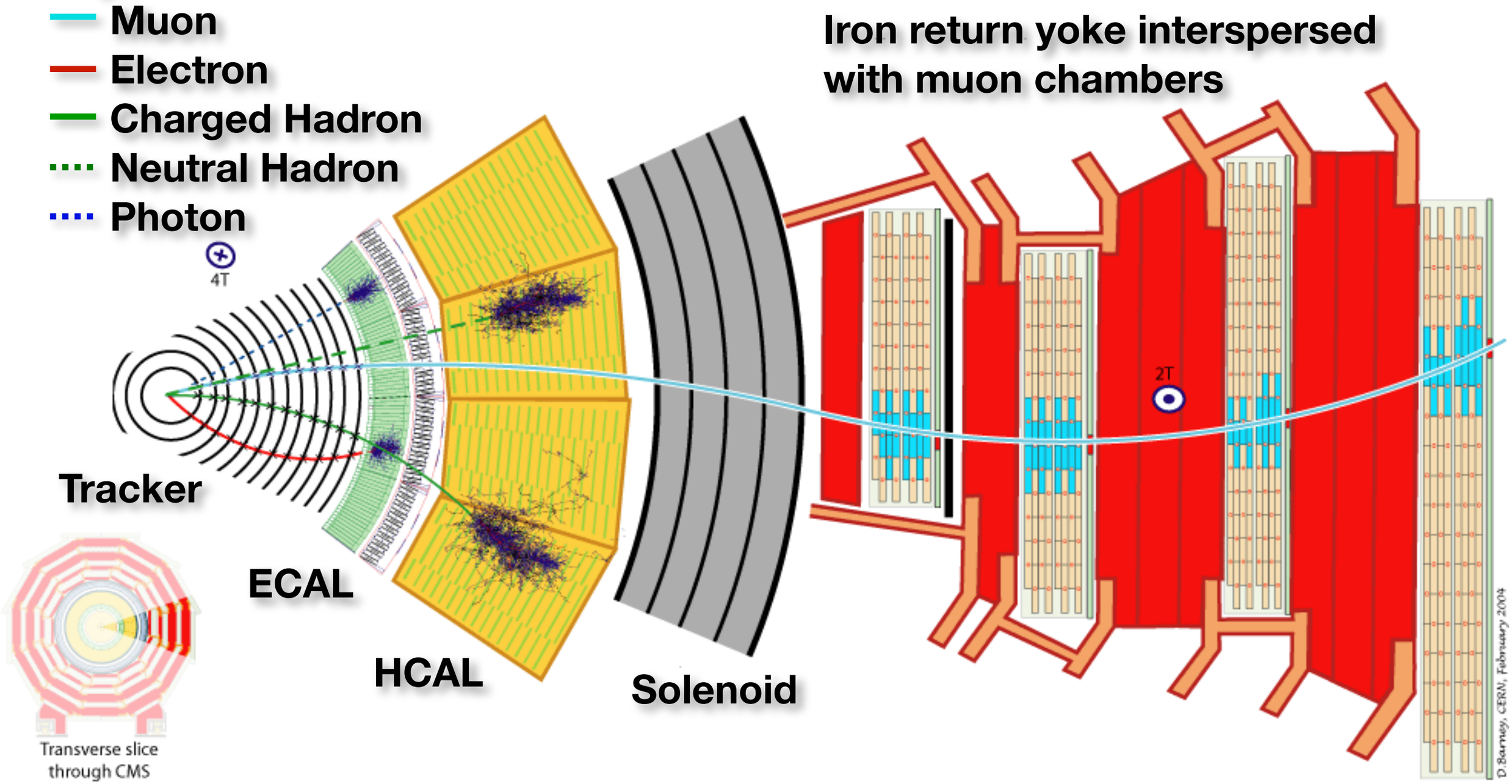
CMS Detector



Particle Detection at CMS

Key:

- Muon
- Electron
- Charged Hadron
- Neutral Hadron
- Photon

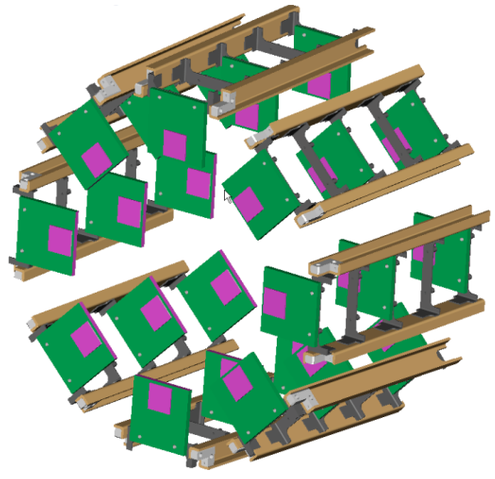


A New Detector

- Tracker: Pixel and strip repairs, validated readout at -20C
- ECAL: new optical trigger links, re-written trigger control software,
- HCAL: new PMTs in the forward HCAL, updated front & back-ends
- Muons: new sector collectors (DT), new chambers (RPC, CSC), refurbished electronics (CSC)
- BRIL: new pixel luminosity telescope, new beam halo monitor
- DAQ: redesigned Level-1 trigger, new DAQ architecture with higher throughput, online cloud

PIXEL LUMINOSITY TELESCOPE (PLT)

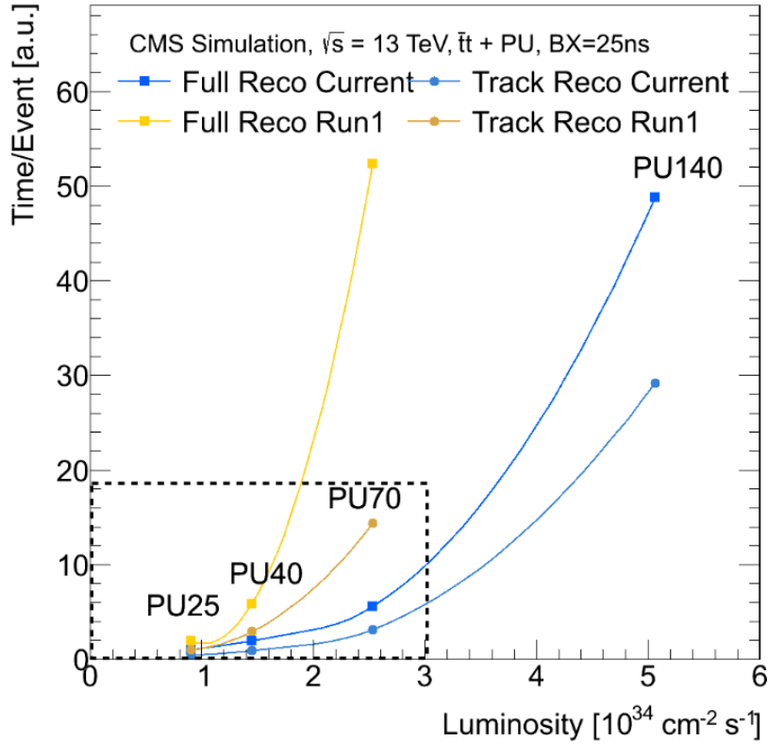
- Two sets (one on each end of CMS) of 8 telescope arrays
  - silicon pixel sensors
  - 5 cm radially from beam pipe
  - 1.8 m from central collision point

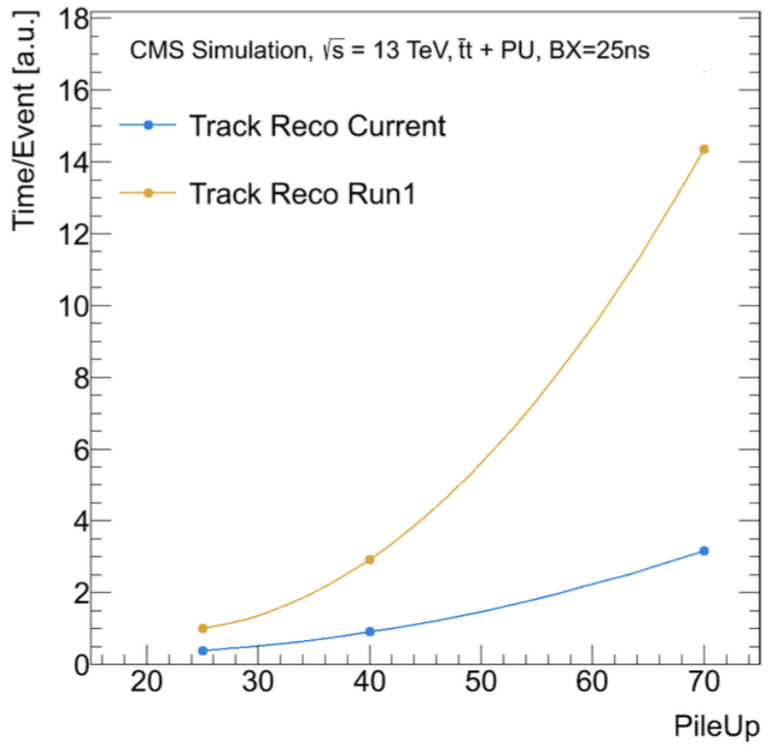


- measure bunch-by-bunch relative luminosity
  - fast-or mode: 40 MHz readout
    - luminosity proportional to three-fold coincidences
  - offline mode: ~kHz
    - full pixel info for tracking to measure systematic effects and measurement of collision point
- Complements HF and pixel measurements of luminosity

TRACKING IMPROVEMENTS

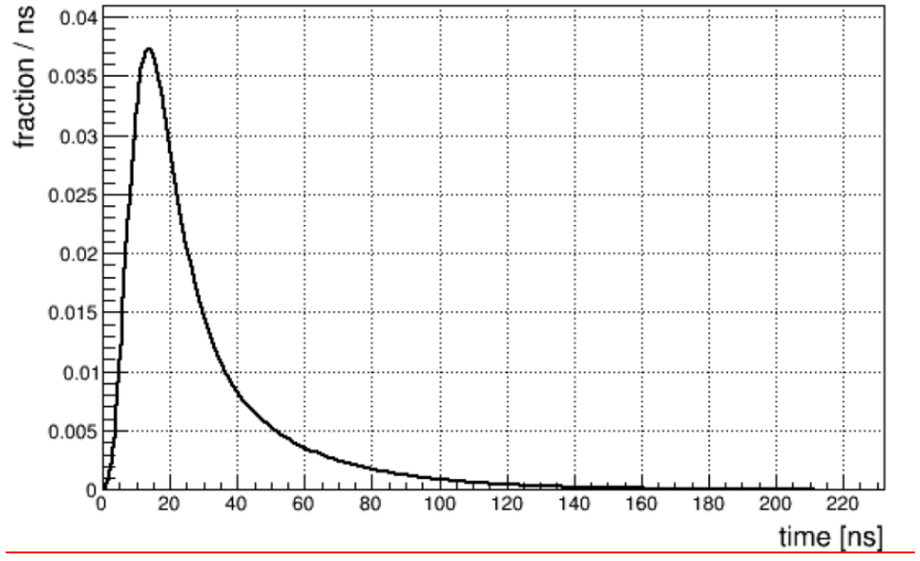
- Tracking based on Kalman filter and divided into 4 steps:
  - seeding, pattern recognition, fitting and selection
  - 7 iterations in Run 1 → 10 in Run 2
    - increased iterations target displaced tracks and muons
- Tracker occupancy is a big challenge with increased PU
  - With 25ns bx, OOTPU increases the strip occupancy ~45%
    - (only ~5% for pixels)
  - cut out fake & OOT clusters by selecting on cluster charge and cluster shape
- Seeding is key for robust tracking
  - strips seeded by cluster triplets: reduces combinatorics and timing

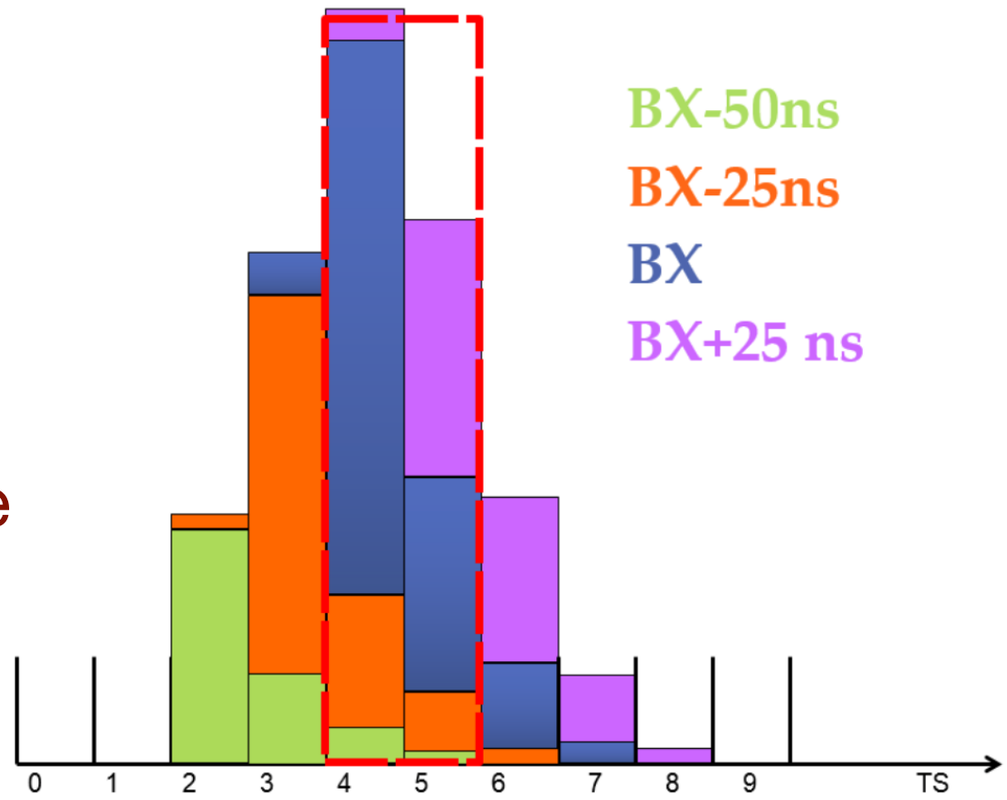




HCAL 25NS RECONSTRUCTION

- signals in HCAL barrel and endcap regions span several 25ns "timeslices"
  - readout 10 TS in total (4 presamples)
- Run 1
  - Summed the total energy in TS's 4&5
- Run 2
  - Given the shape of the pulse as a function of energy, we **fit** for the in-time and OOT contributions
    - Significant suppression of OOT energy, but now more sensitive to the timing

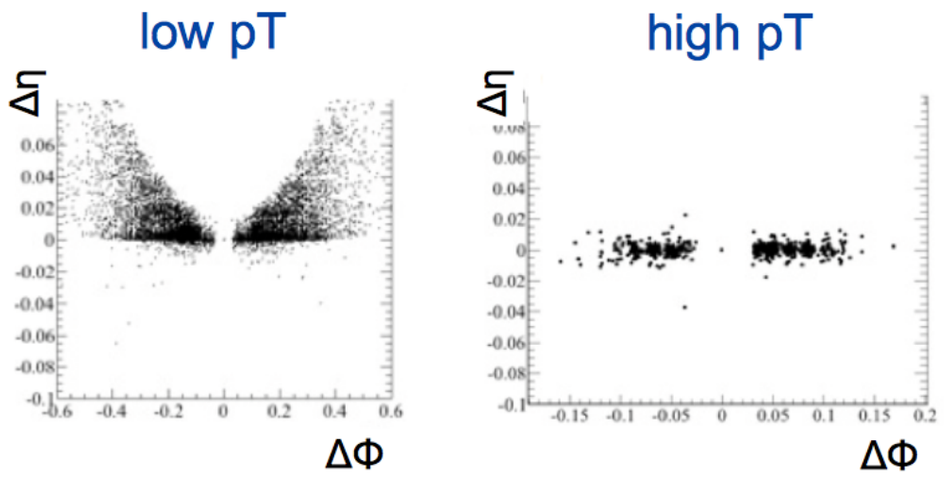


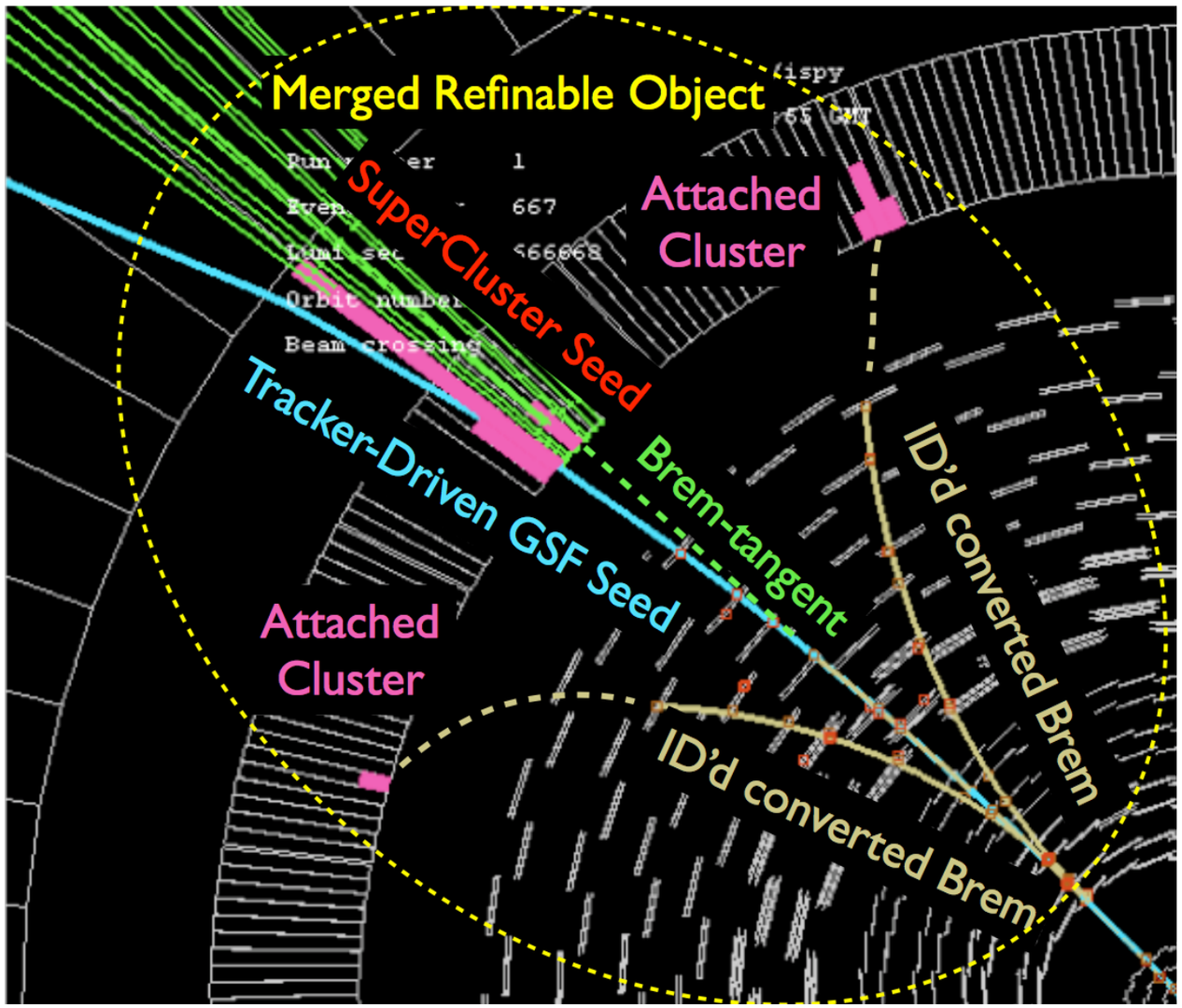


E/GAMMA PARTICLE ID

- New, unified “particle flow” approach to electron&photon ID
  - took lessons from Run1 Hgg analysis and redeployed improvements throughout standard reconstruction framework

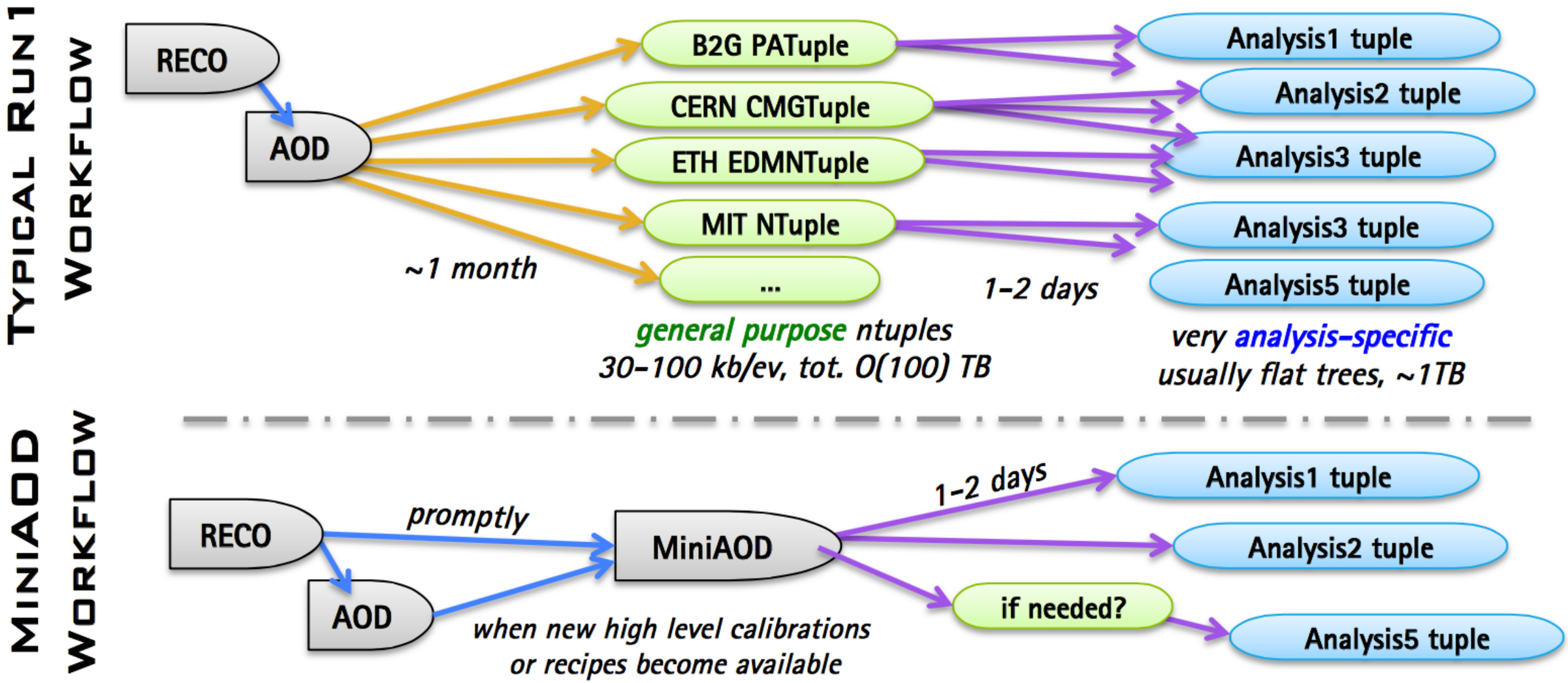
- Mustache superclusters account for eta-phi correlation of cluster shapes





MINI-AOD

- A new, compact, high-level data tier **(30-50 kB/event)** designed to cover mainstream analyses and replace the need for big group-level ntuples
  - produced **promptly and centrally**

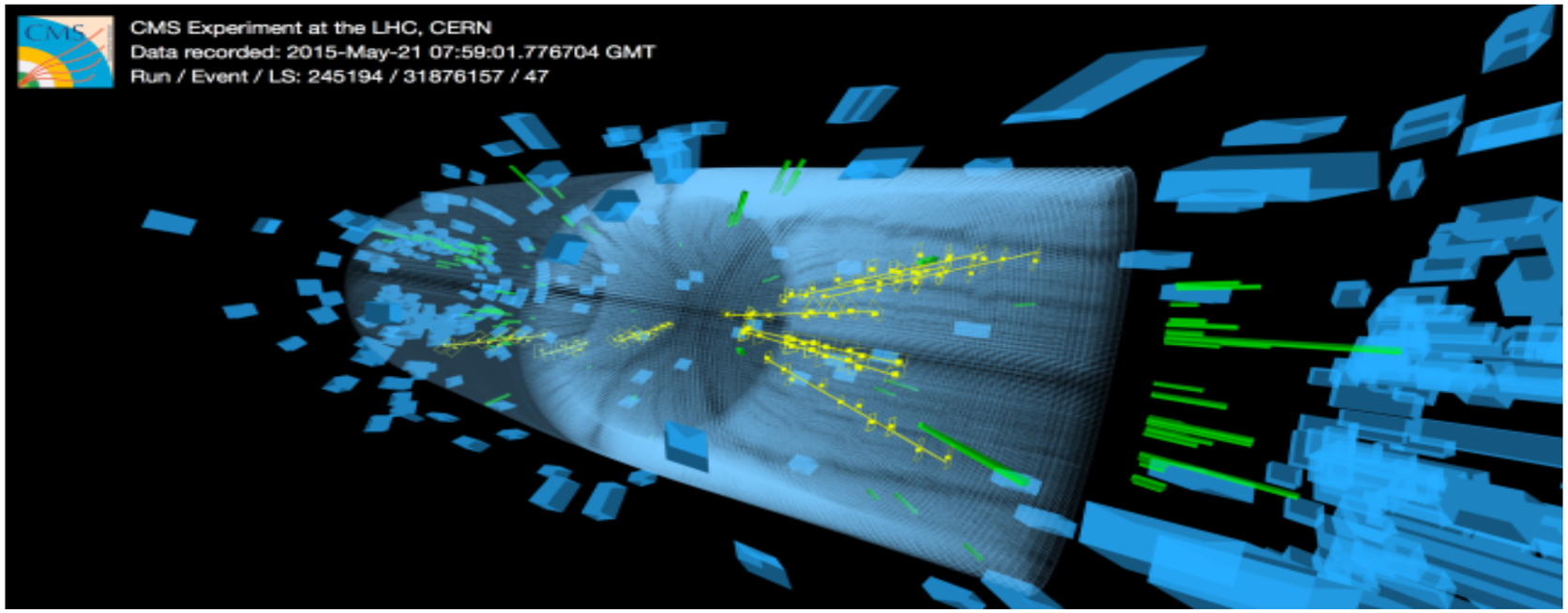


Run 2

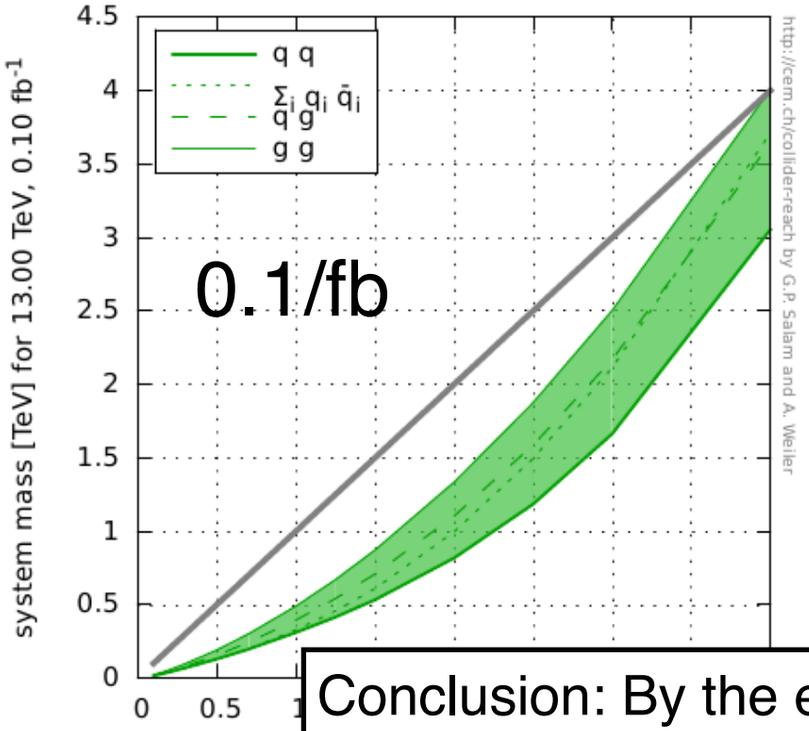
CMS Magnet

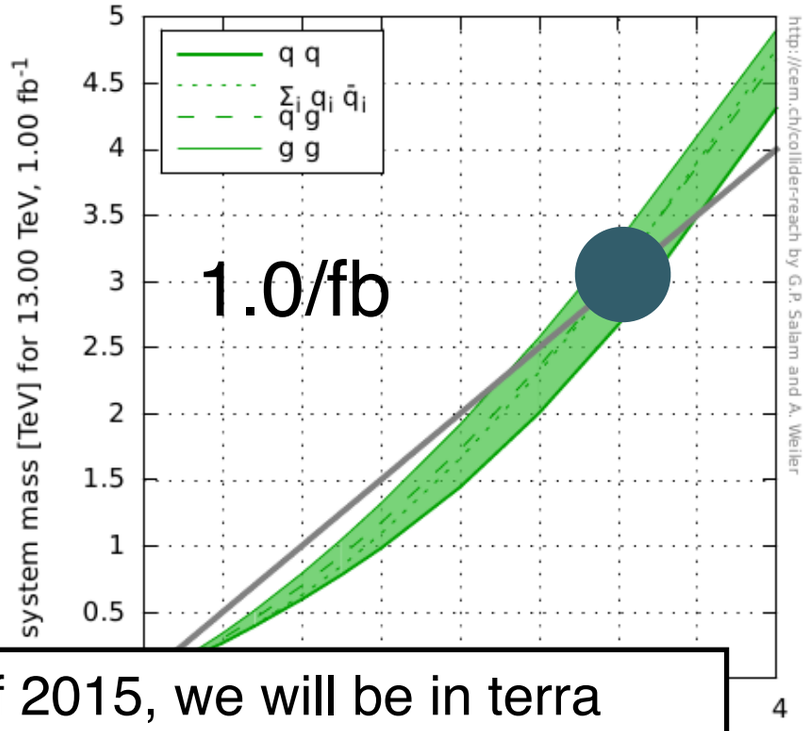
- The restart of the CMS magnet after LS1 was more complicated than anticipated due to problems with the cryogenic system in providing liquid Helium
  - Inefficiencies of the oil separation system of the compressors for the warm Helium required several interventions and delayed the start of routine operation of the cryogenic system
    - Currently the magnet can be operated, but the continuous up-time is still limited by the performance of the cryogenic system requiring more frequent maintenance than usual.
- Recent performance has been encouraging
  - All data collected since the 24th of September has been with the magnetic field turned on
  - corresponds to >600/pb of data
- A consolidation and repair program is being organized for the next short technical stops and the long TS at the end of the year

First Collisions at 13 TeV

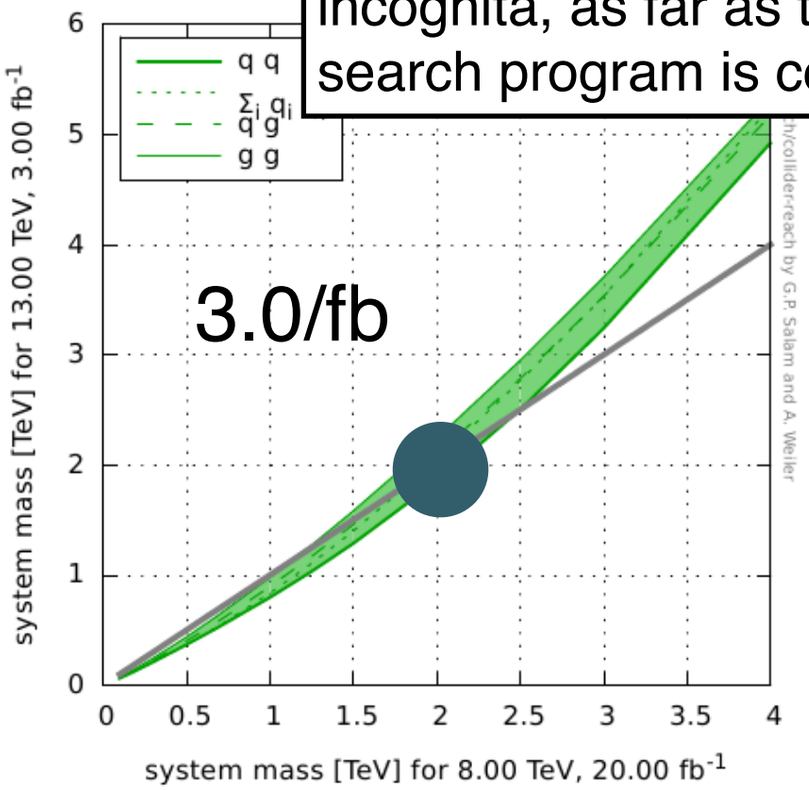


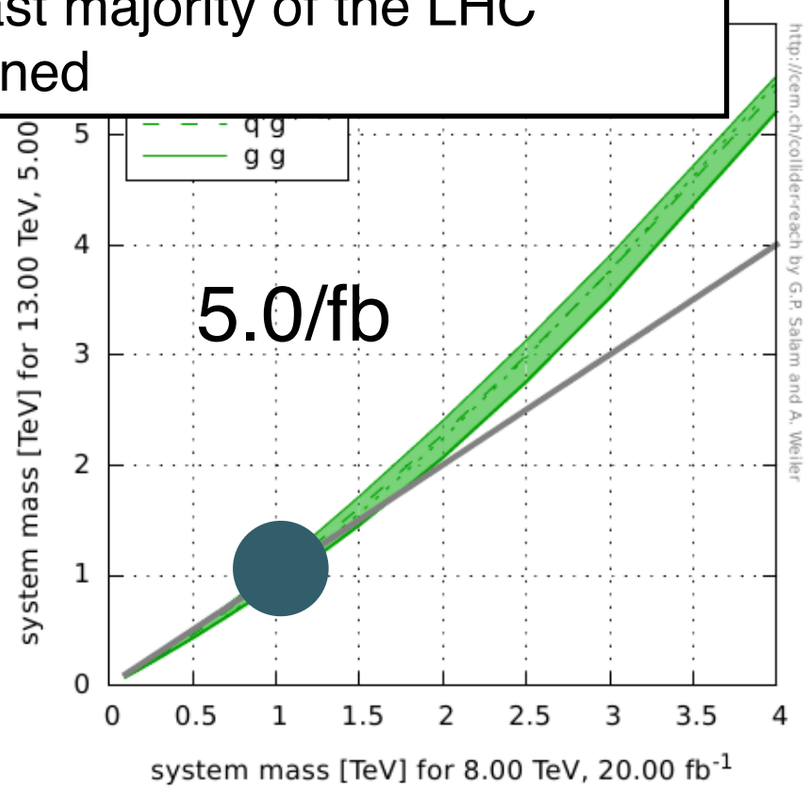
2015 LHC Reach





Conclusion: By the end of 2015, we will be in terra incognita, as far as the vast majority of the LHC search program is concerned

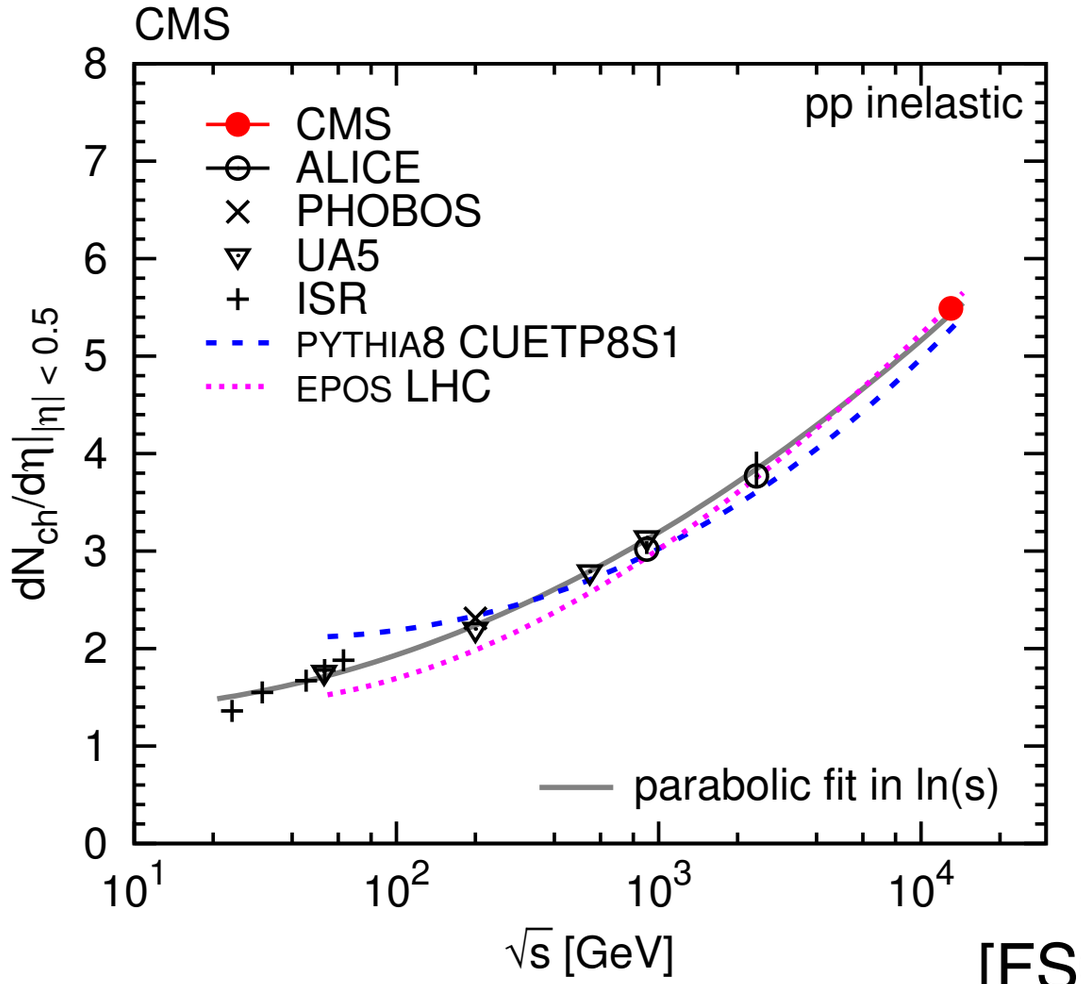


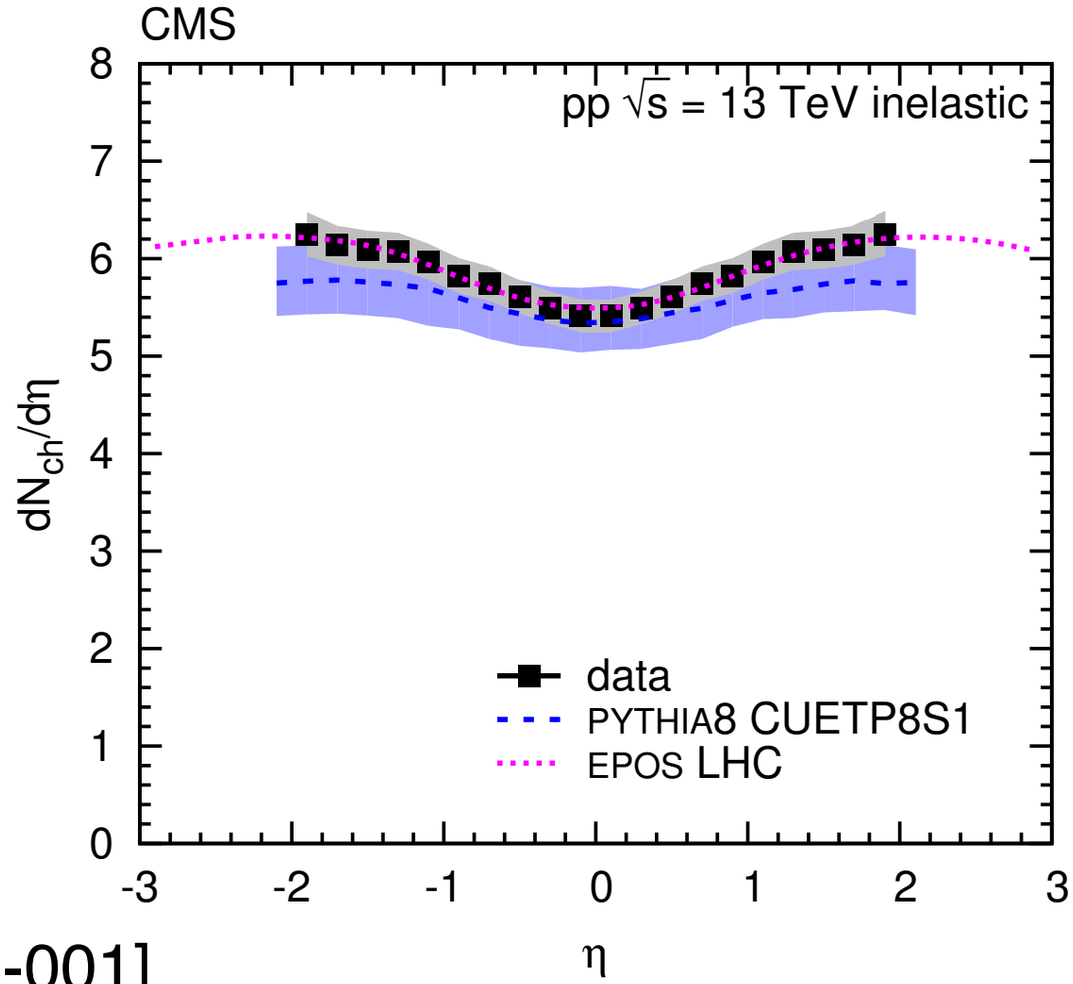


- With 1/fb we have added sensitivity to ~3 TeV objects
  - (~1.5 TeV for pair production)
- With 5/fb we have added sensitivity to ~1 TeV objects
  - (~0.5 TeV pair production)

First CMS Physics Result

- dN/dη measured in the central |η|<2.0 region of the detector
  - operated with B=0 T
  - dN/dη=5.49 ± 0.01 (stat) ± 0.17 (syst) for |η|<0.5
  - First paper submitted by an LHC experiment on the 13 TeV collisions

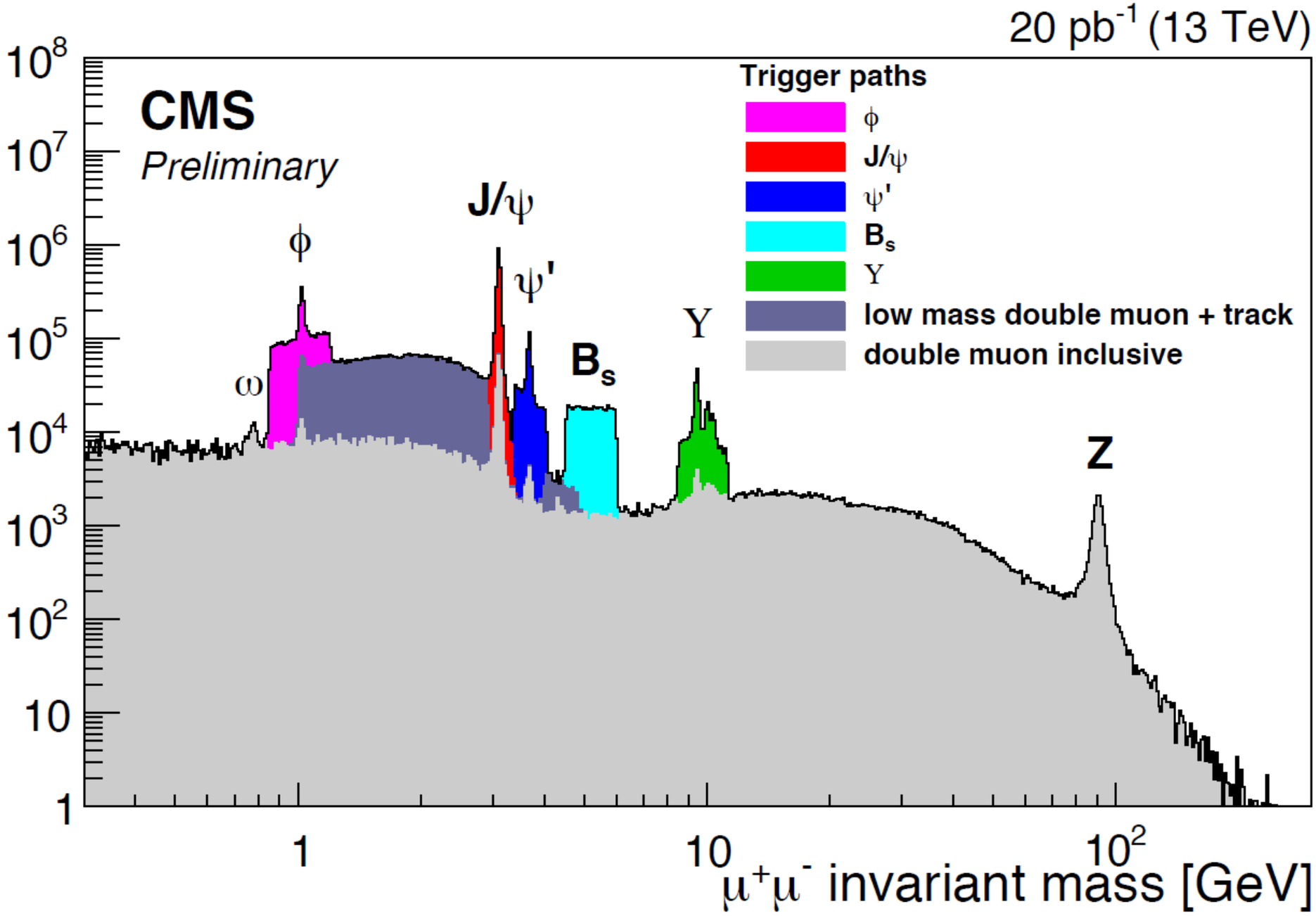




[FSQ-15-001]

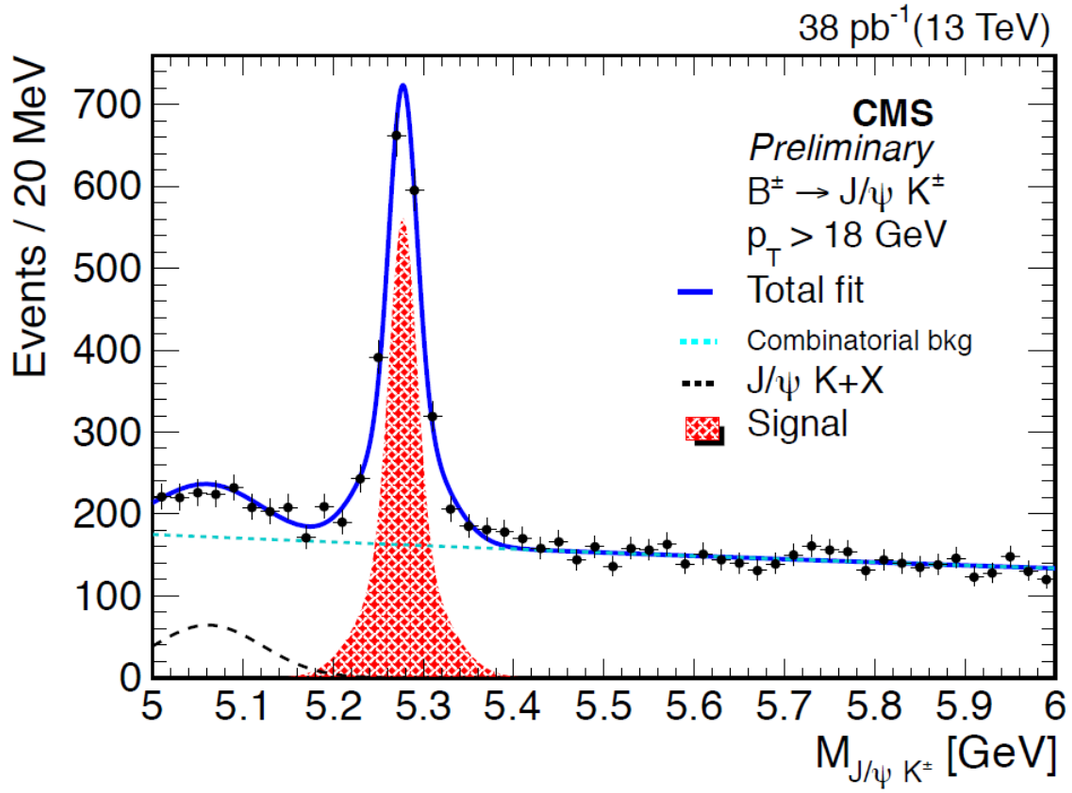
TRIGGER PERFORMANCE

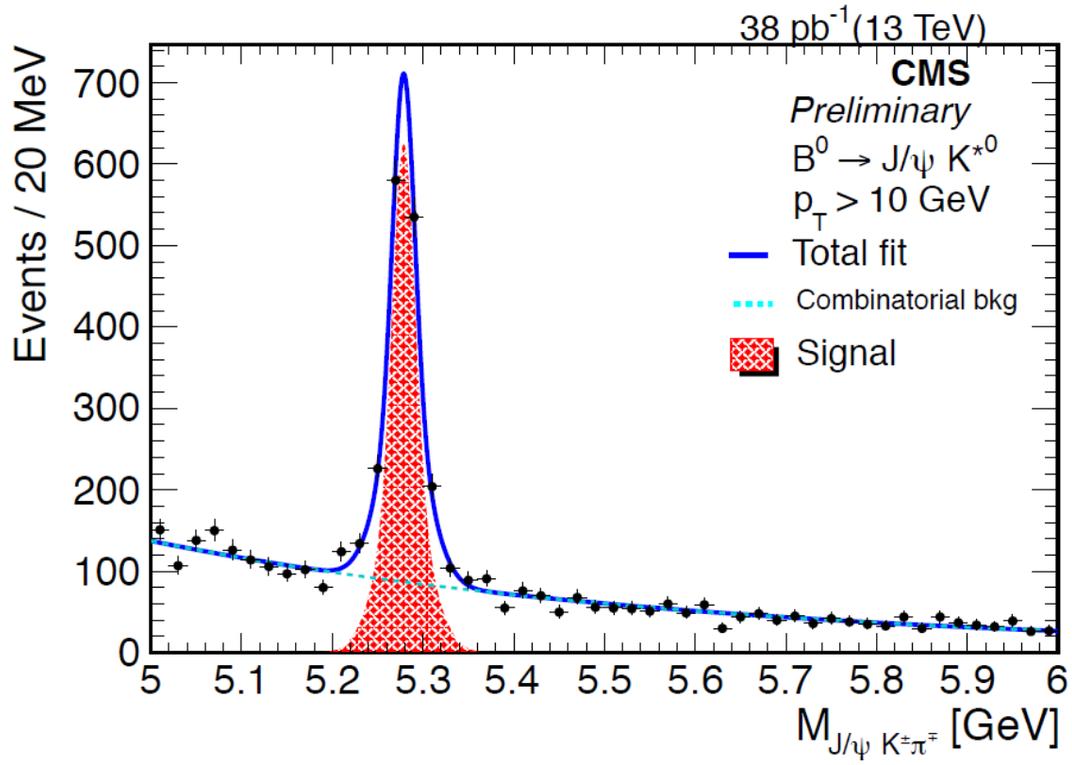
- Specialized double muon triggers in select invariant mass windows and with pT cuts



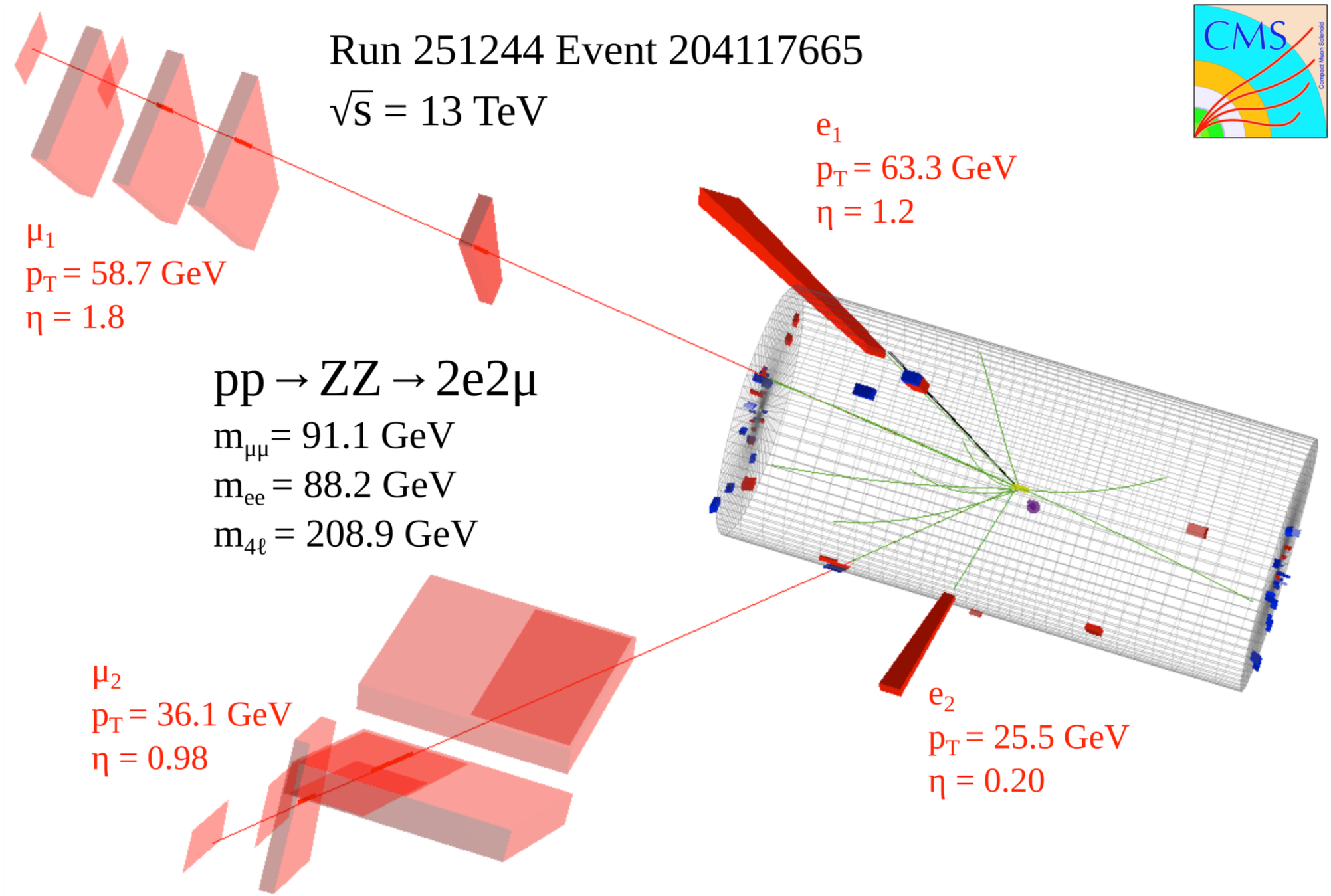
RESONANCES

- $B^{\pm} \rightarrow J/\psi\ K^{\pm}$
  - taken with inclusive J/ψ trigger
    - Mass: 5277 ± 1 (stat) MeV
    - PDG: 5279.26 ± 0.17 MeV
- $B_s \rightarrow J/\psi\ \phi$
  - taken with displaced J/ψ and track trigger
    - Mass: 5369 ± 1(stat) MeV
    - PDG: 5366.7 ± 0.4 MeV

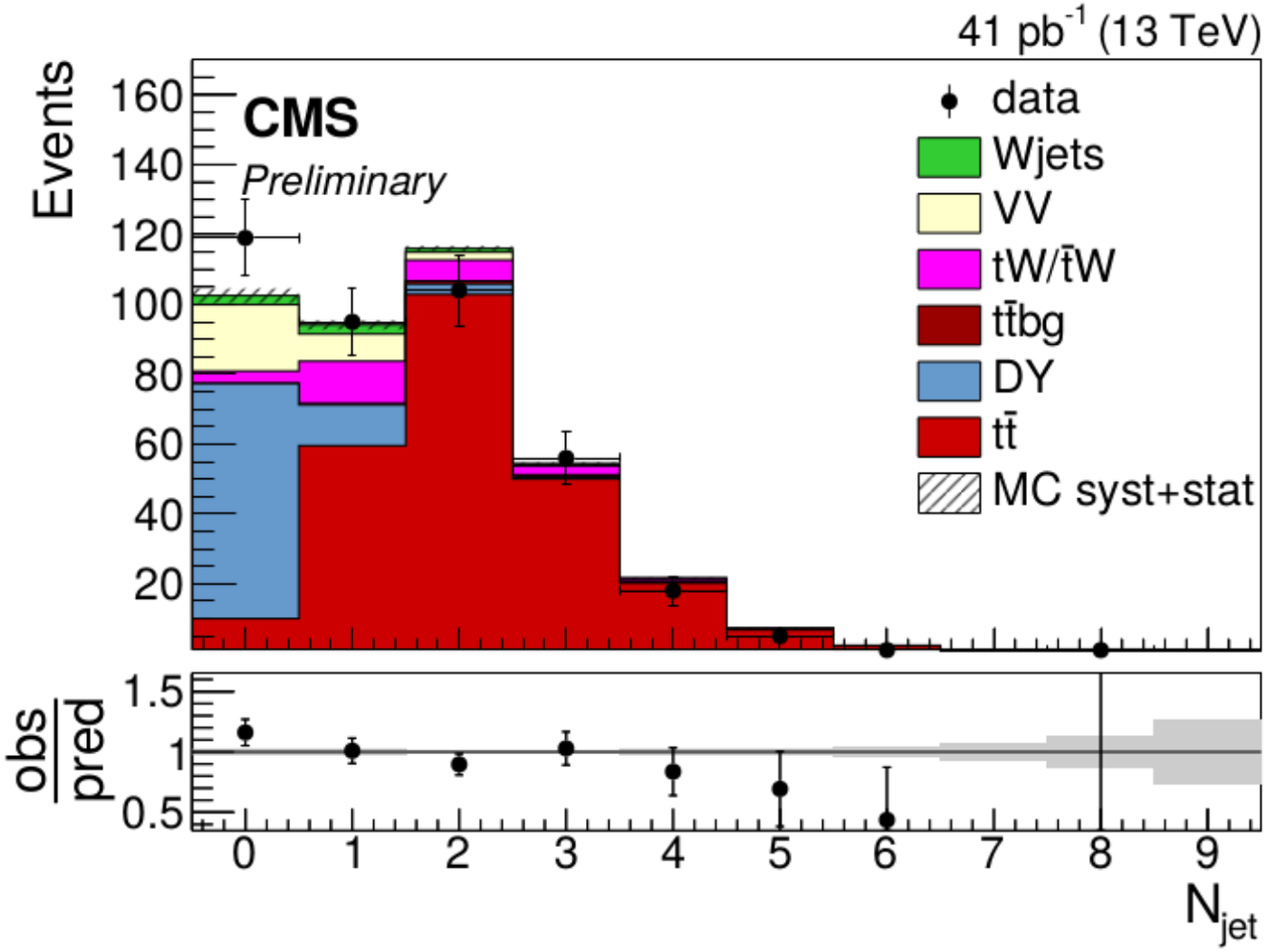


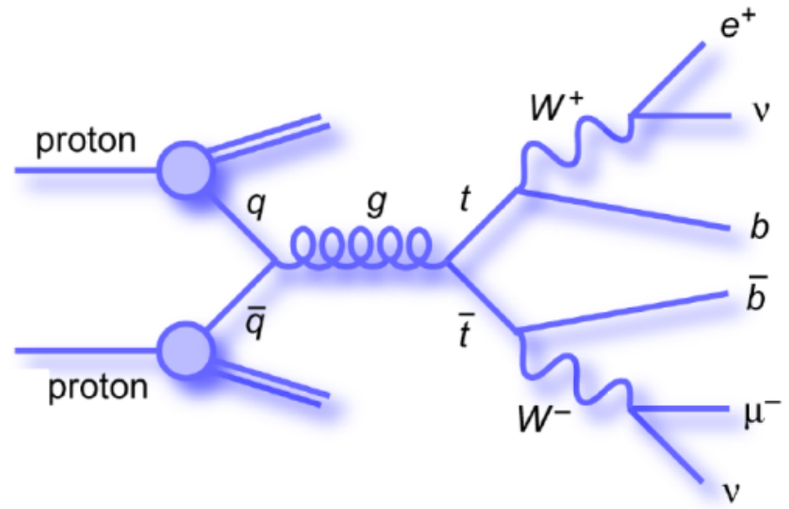


Z to 4 Leptons



Top (Re-)Discovery

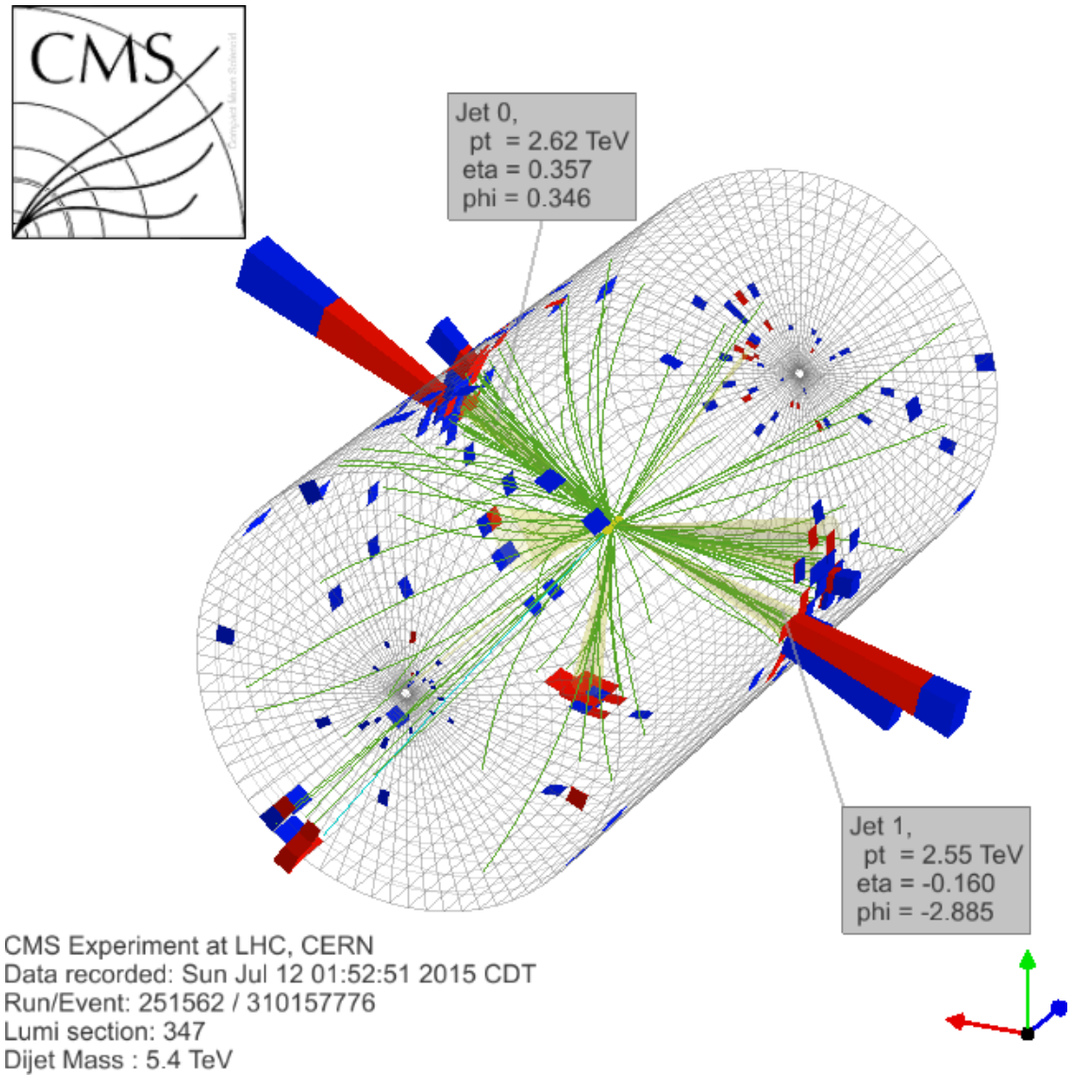


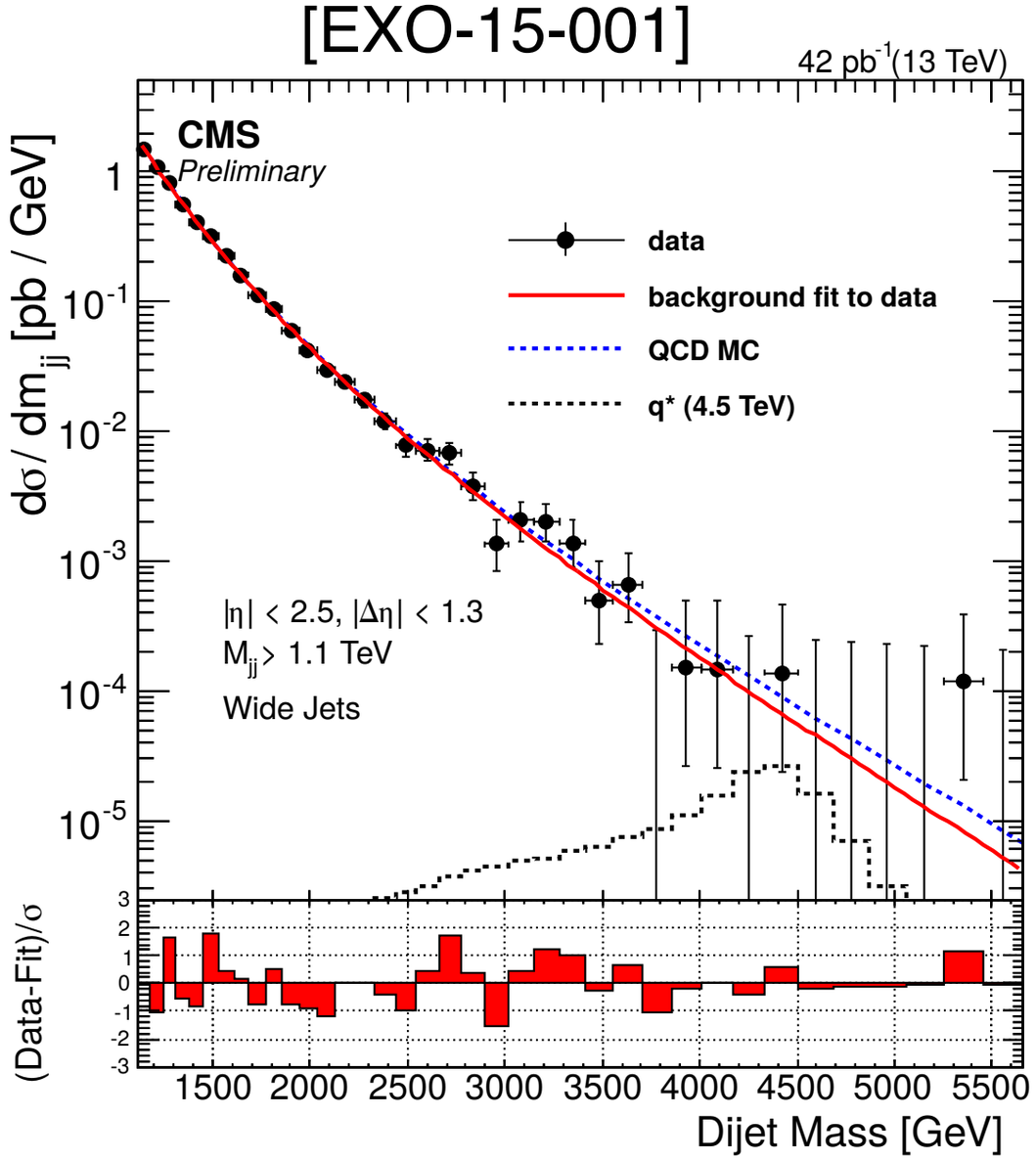


- Number of hadronic jets for events containing one isolated muon and one isolated electron forming an invariant mass greater than 50 GeV.

DIJET RESONANCES

- Probing new energy scales with 42/pb of data!
  - Set new limits on string resonances at 5.1 TeV

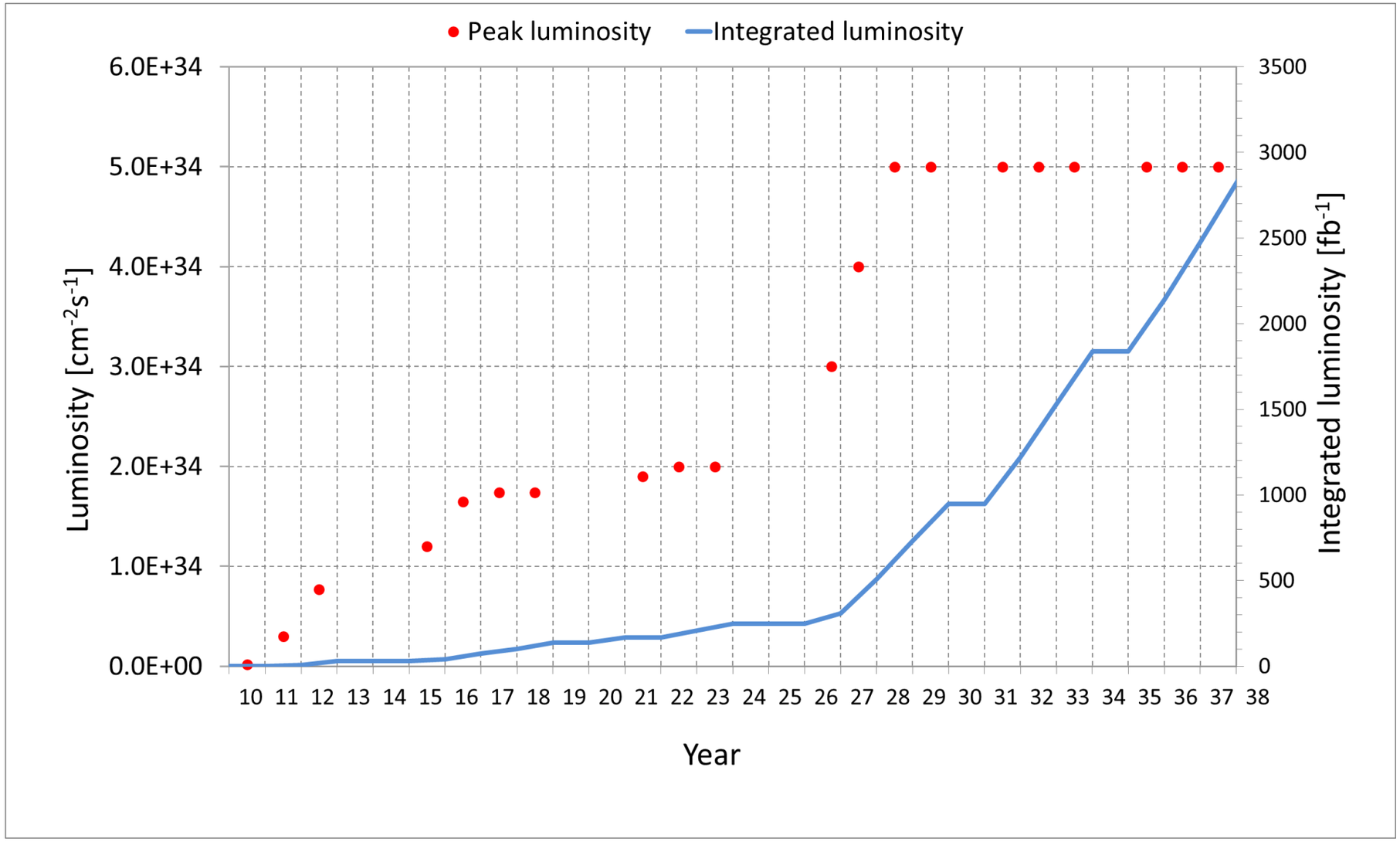




Model	Final State	Obs. Mass Limit [TeV]	Exp. Mass Limit [TeV]
String Resonance (S)	qg	5.1	5.2
Excited Quark (q*)	qg	2.7	2.9
Scalar Diquark (D)	qq	2.7	3.3
Axigluon (A)/Coloron (C)	qq̄	2.7	2.9
Color Octet Scalar (s8)	gg	2.3	2.0

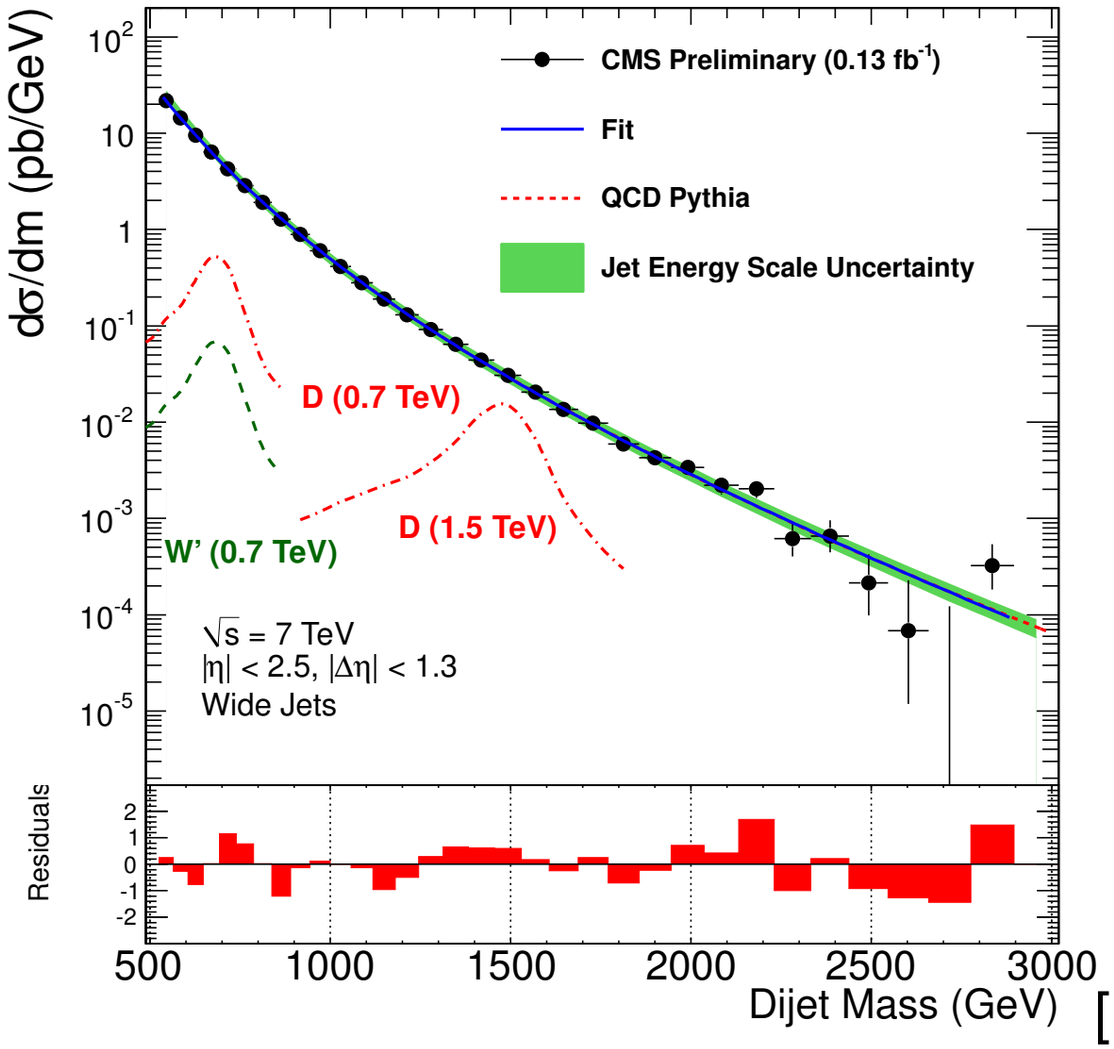
The Future

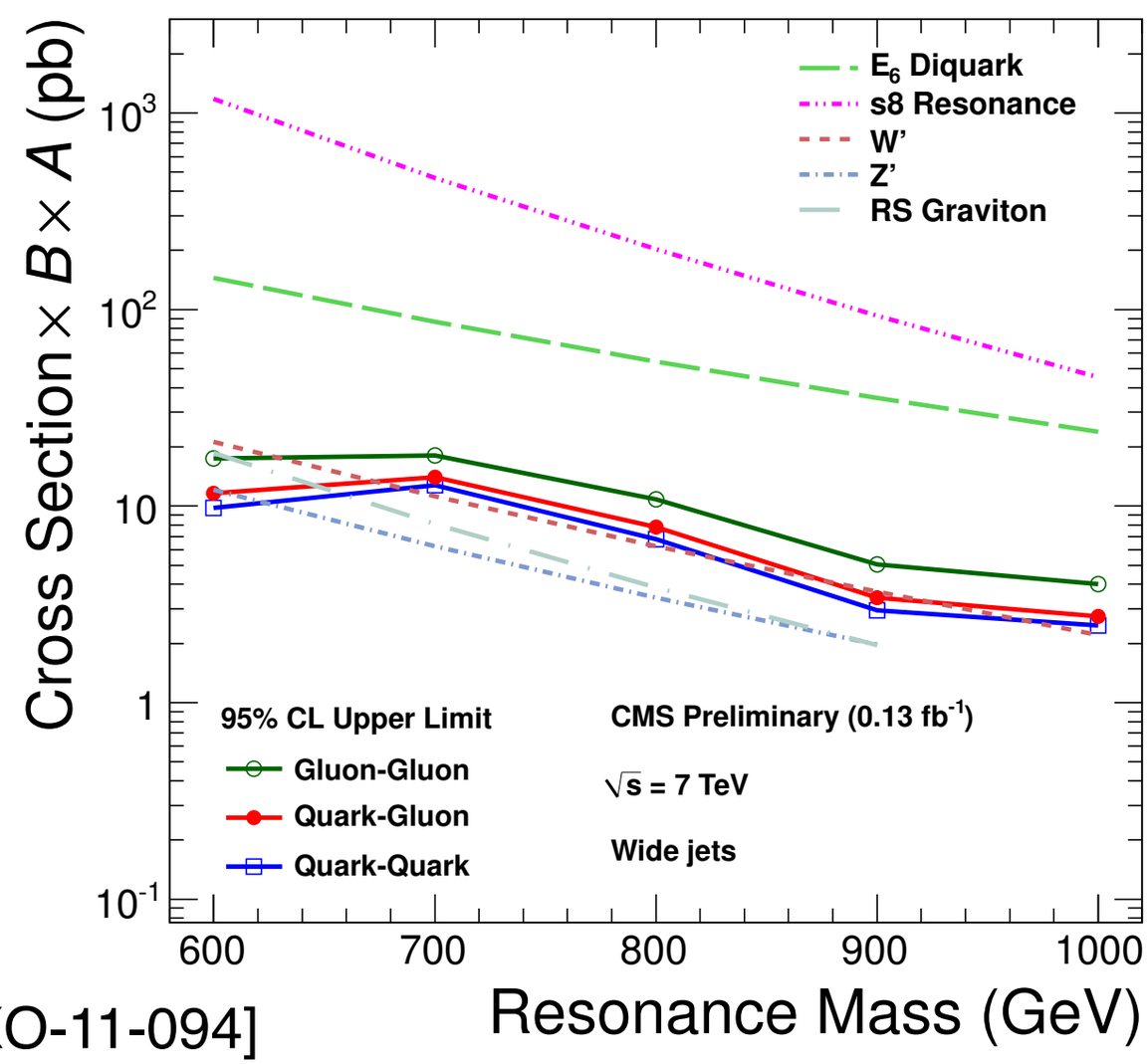
- What we have in store for the next few years…
  - (Assuming leveling at 5e34)
    - However, if we want to discover new physics, it's likely to happen early…



Data Scouting

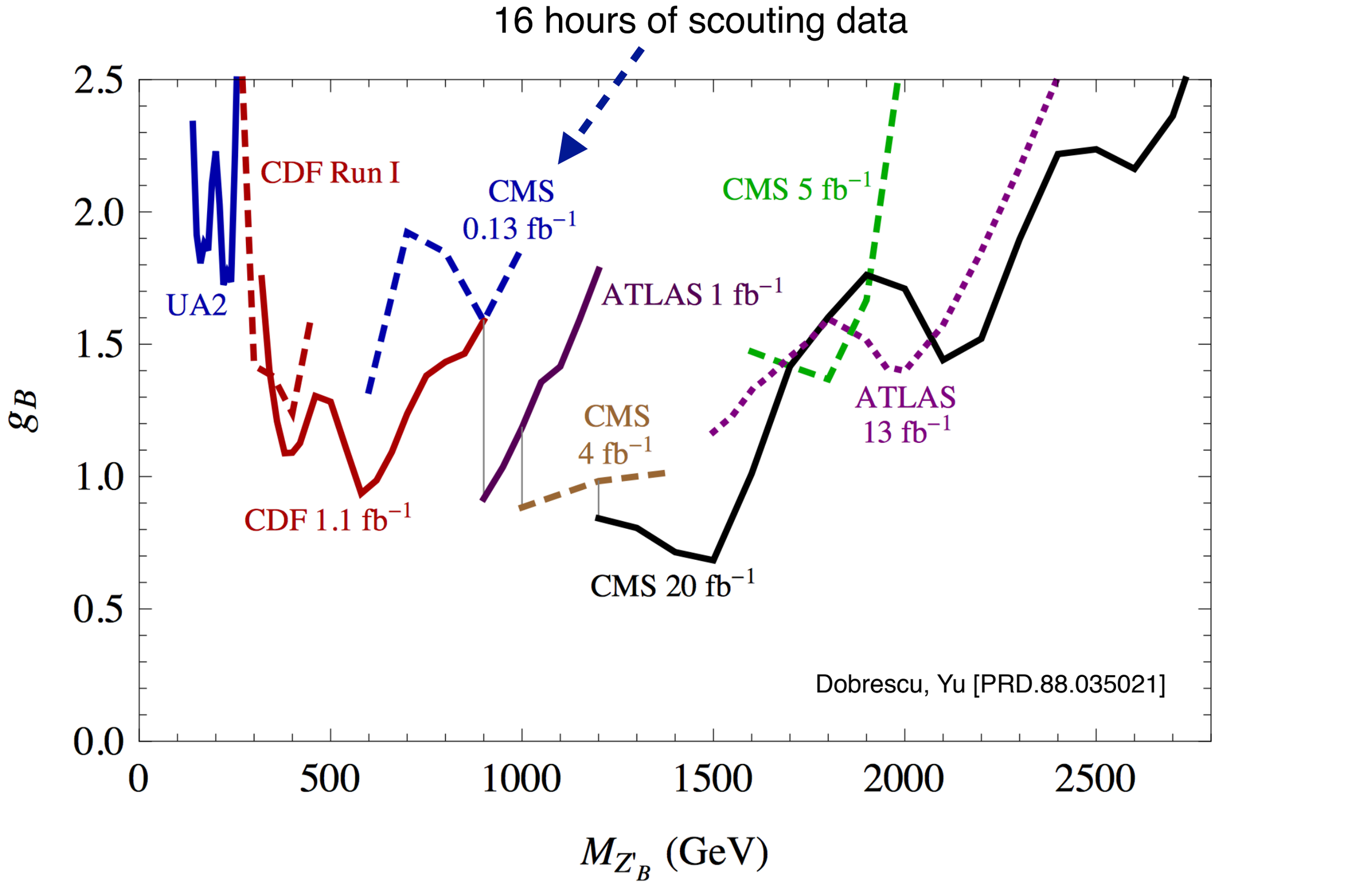
- Novel trigger, DAQ, and analysis strategy to search below 1 TeV
  - Low jet-trigger thresholds means high event rate (~KHz)
  - Store reduced data format <5 Kb/event





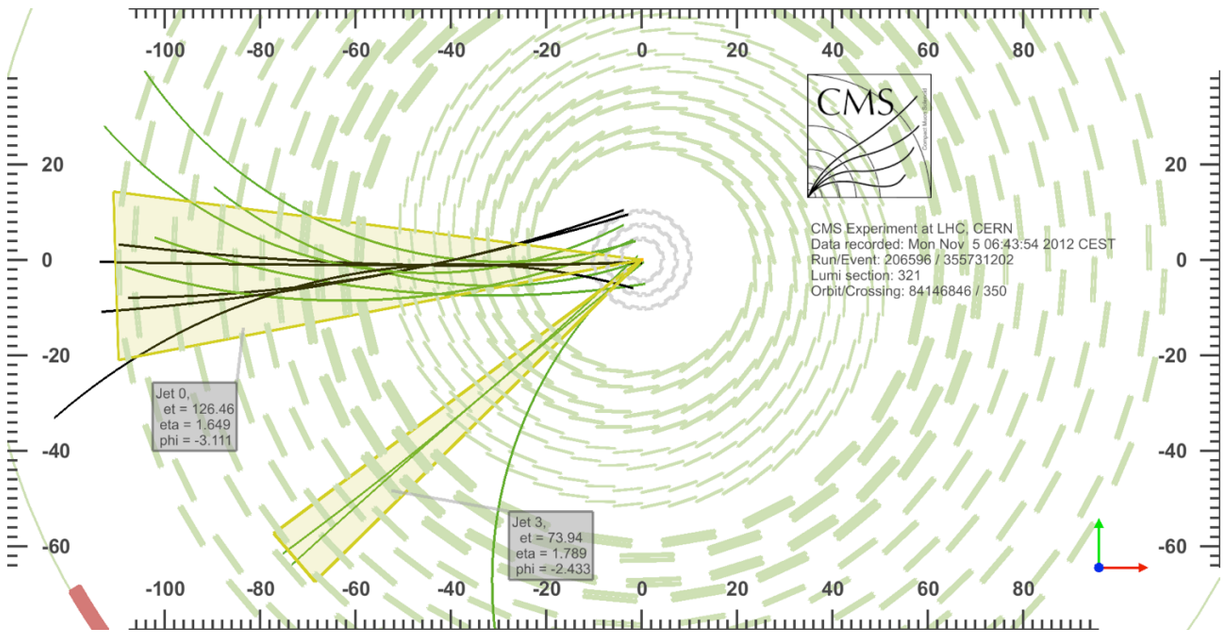
[EXO-11-094]

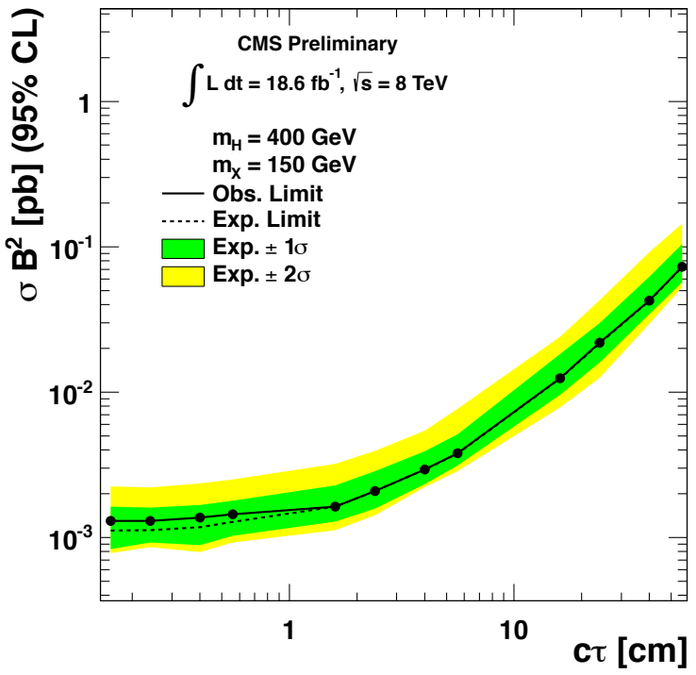
DATA SCOUTING



DISPLACED JETS

- Massive long-lived particles can decay to jets
  - Split SUSY, RPV SUSY, Gauge Mediated SUSY, Hidden Valley models, etc.
- Search for events with **dijets from a common, displaced vertex**
  - Trigger on events with H_T>300 GeV and **≥2 jets with small fraction of prompt tracks**
    - Offline: form multivariate discriminant based on vertex track multiplicity, fraction of tracks with positive d0, # of missing hits, and variables from a **dedicated track clustering algorithm**

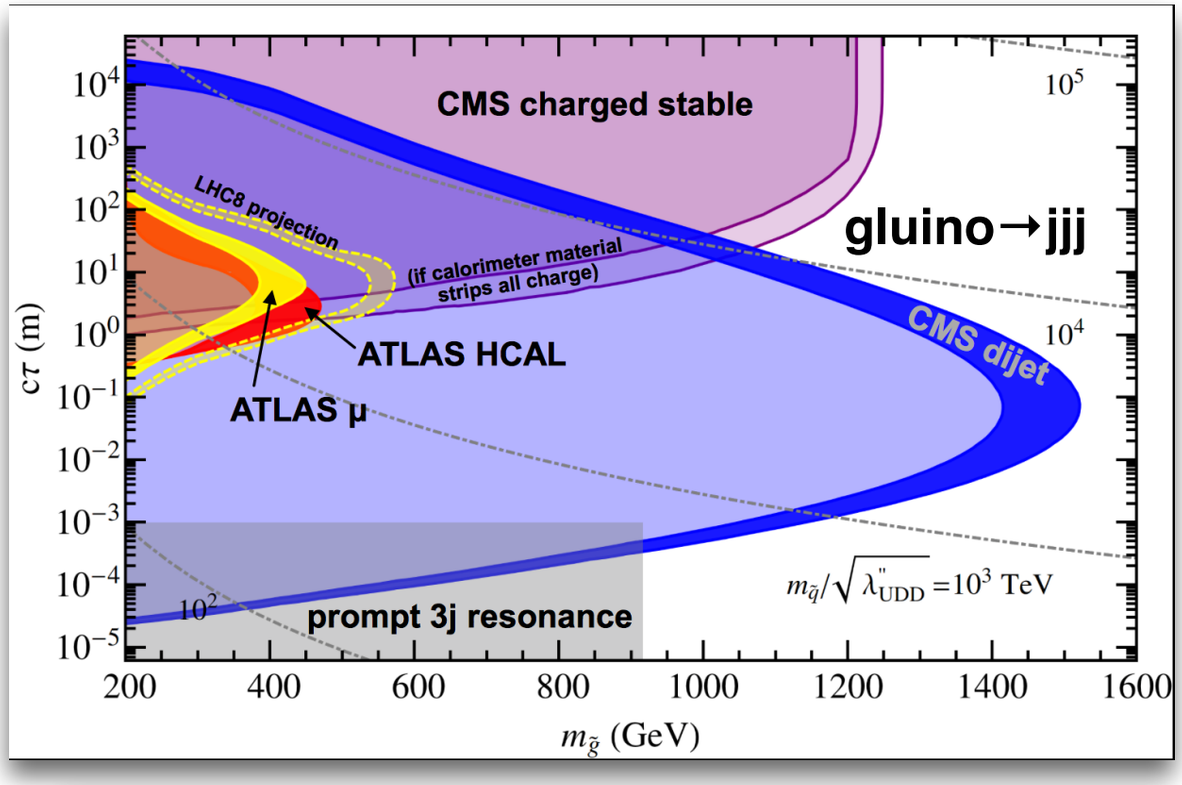


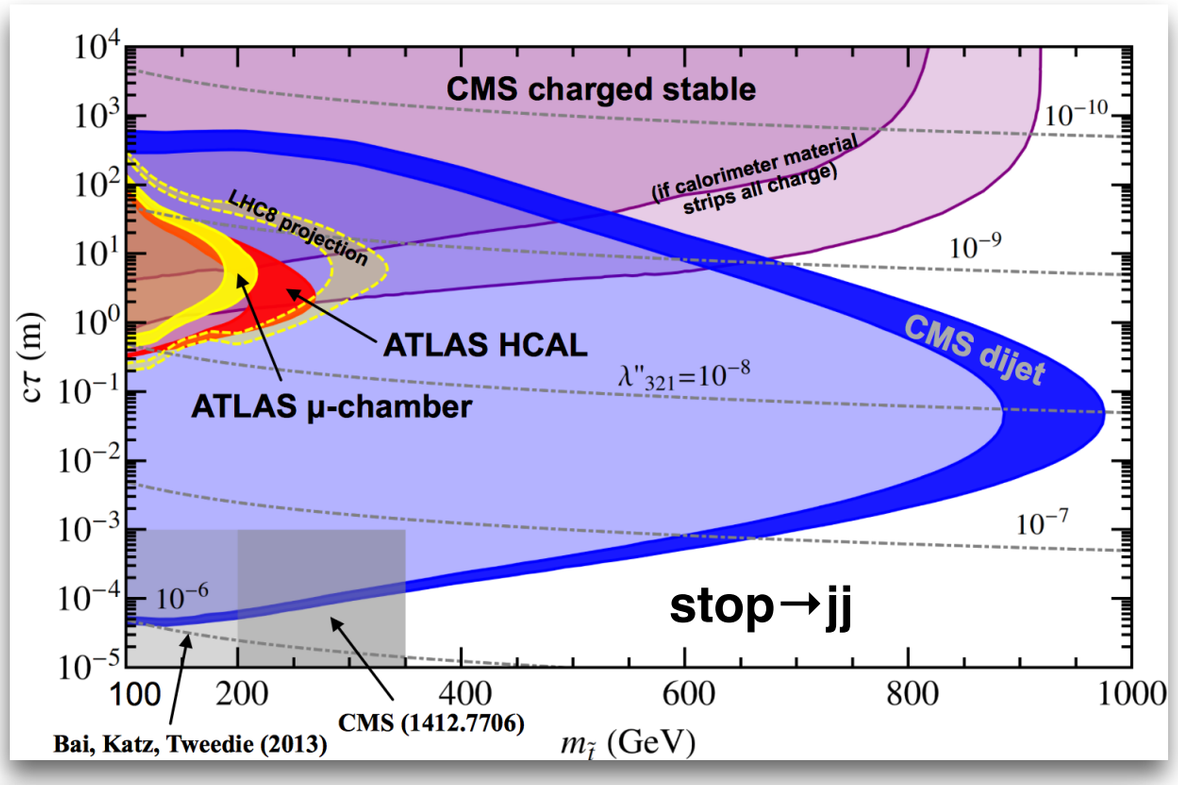


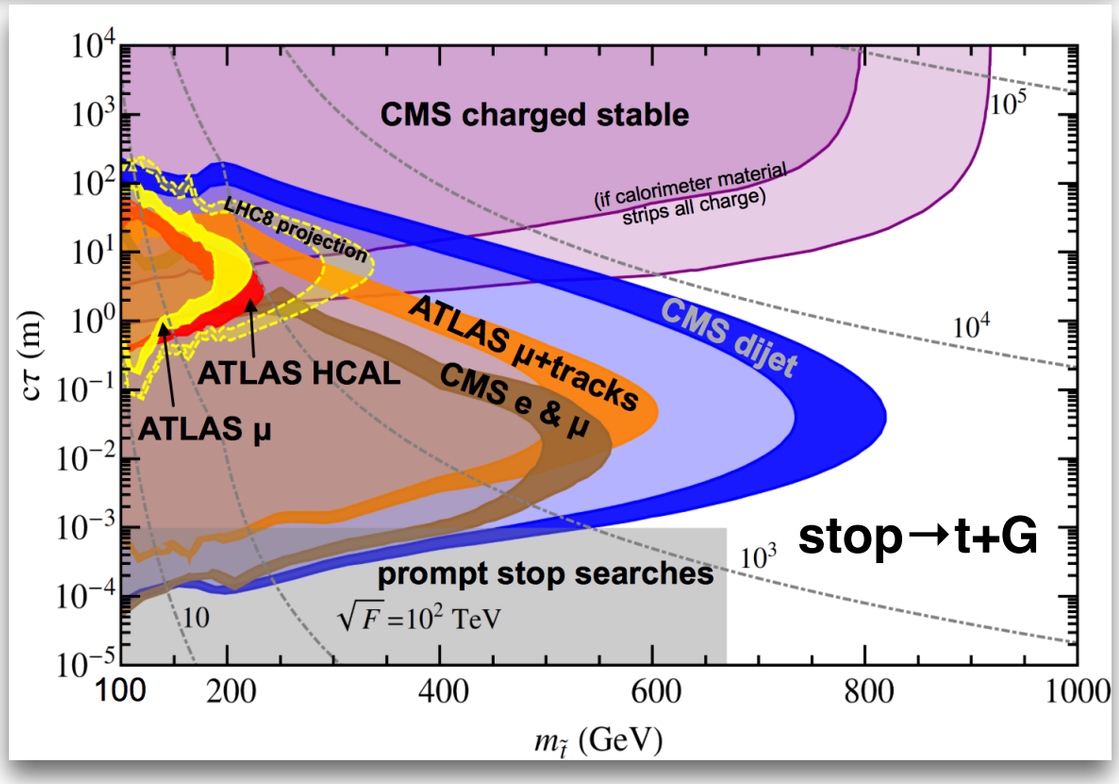
[EXO-12-038]

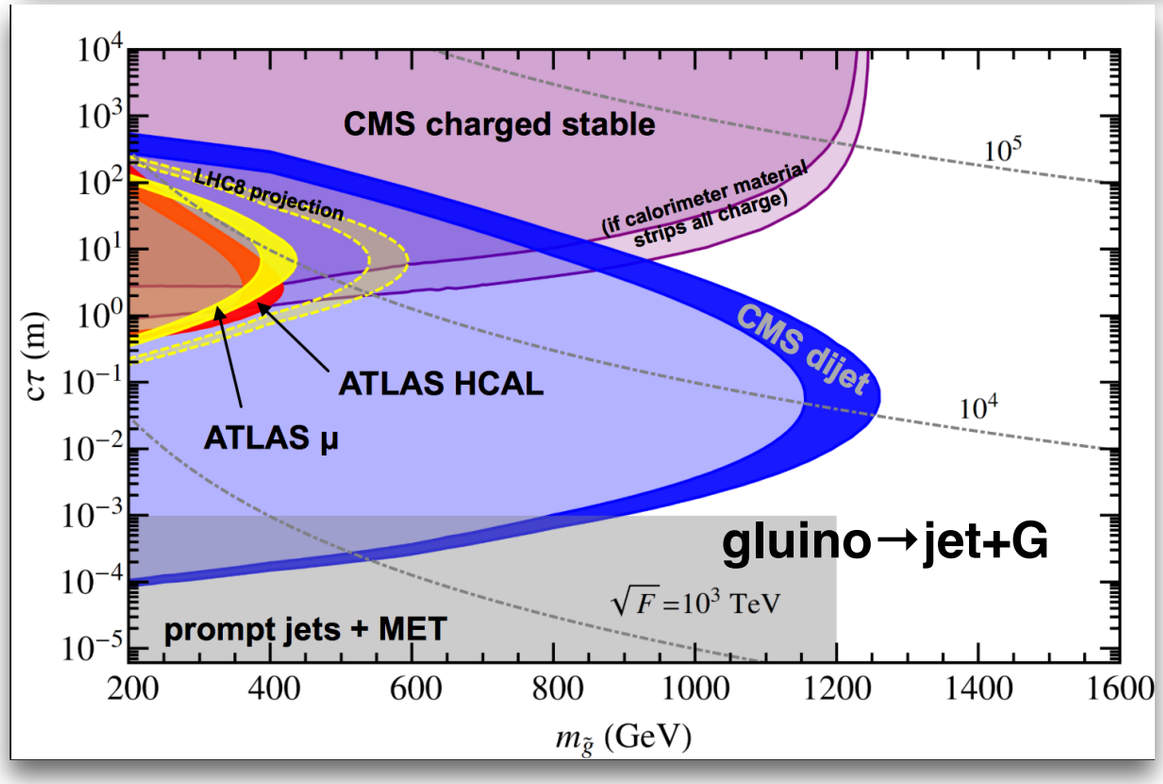
DISPLACED JET SENSITIVITY

Liu, Tweedie [arXiv:1503.05923]









CONCLUSIONS

- 2015 will be an exciting opportunity to discover new physics, however it shows up
  - CMS is in a strong position to take advantage of the new energy and luminosity afforded by the upgraded LHC
    - in many cases, we're as good if not better than in Run 1, despite the significantly more challenging conditions
  - of course, lots of unknown unknowns